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ABSTRACT

Science educators face the challenge of a massive reform movement which calls for a re-examination and revitalization of science curriculum and pedagogy. The purpose of this research was to illuminate the phenomenon of analogy use in science classrooms by exploring the process and influence of analogies. Qualitative and quantitative techniques were used to study the use and effectiveness of teacher-generated analogies, student-generated analogies, and traditional instruction. Participants in the study were 269 8th-grade students enrolled in a public school district in a northern suburb of Chicago. Analysis of the data indicate that instruction with analogies was more effective than traditional methods of instruction. The success of the analogies was found to depend on the student's prior knowledge, the type of analogy used, and the goal of the analogy. Contains 155 references. (Author/JRH)

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CELLS ARE SIMILAR TO FACTORIES:
ANALOGIES IN SCIENCE

Kim M. Pittman

Educational Psychology Doctoral Program

Submitted in partial fulfillment
of the requirements of
Doctor of Education
in the Foster G. McGaw Graduate School

National College of Education
National-Louis University

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Abstract

Science educators face the challenge of a massive reform movement which calls for a re-examination and revitalization of science curriculum and pedagogy. Among the recommendations under consideration by the National Science Teacher's Association (NSTA) is the utilization of more constructivist strategies within the classroom.

The purpose of this research was to illuminate the phenomenon of analogy use in science classrooms by exploring the process and influence of analogies. In pursuit of this goal, the researcher conducted a combined quantitative and qualitative study on the use and effectiveness of teacher-generated analogies, student-generated analogies and traditional instruction. Observations, interviews, and test scores provided the data from which several findings emerged.

The analysis of the data provided the following conclusions. Instruction with analogies was more effective than traditional methods of instruction of protein synthesis to eighth grade science students. Analogies were successful under certain conditions. These conditions included the amount of prior knowledge, the type of analogy used, and the goal of the analogy. Students with more prior knowledge in science performed better with the analogies than did the students with less background knowledge. Students with more science knowledge created and utilized analogies differently than students with less science knowledge.

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Chapter 1

RATIONALE

> *Julie, a very bright eighth grader, is asked to explain the mechanisms causing the seasons and the phases of the moon. She has not received any formal instruction on these topics in her eighth grade science class; however, these topics were covered in science lessons from earlier grades. During the course of her explanations, Julie displays some misconceptions. For example, Julie believes that the earth orbits the sun in a bizarre "curlicue" pattern, and that the seasons are caused by the proximity of the earth to the sun at different times during the orbit. In terms of explaining the phases of the moon, Julie believes that the shadow of the earth on the moon causes the phases.*

This scenario is not fiction. It summarizes events that actually transpired during a class discussion in a school in a Midwestern city. Julie clearly has formed a mental representation that mixes both erroneous and correct ideas into a muddled package. The problem with these incorrect notions is that many are unlikely to change as a result of instruction. Julie is not unique; in fact, she is in good company. Interviews of some Northwestern graduates revealed the same misconceptions; however, these graduates delivered their explanations with much more conviction (Mestre, 1994).

Scenarios like this are more the norm than the exception in American schools. Students from kindergarten to college who are taught by competent teachers, are emerging from science courses with a very poor understanding of both scientific concepts, and of the nature of science in general (Mestre, 1994).

It is against this backdrop that the recent educational reform movement in science has emerged. The new science benchmarks (National Research Council,1996) suggest that only " a limited number of important concepts, principles, facts, laws and theories" be taught. Further, these national standards suggest that these foundation concepts should be what we call big ideas (or foundation concepts) that represent central scientific ideas and organizing principles of science. These big ideas have rich explanatory and predictive power, motivate the formulation of significant questions and are applicable to many situations and context. Research findings support the educational value of organizing science content around big ideas for better learning and greater instructional efficiency (Woodward, 1994).

Unfortunately, textbooks usually dominate science instruction in the classroom (Anderson & Smith, 1983). The number of vocabulary words included in science texts almost precludes anything but lists of vocabulary. Often the vocabulary in a one-week science unit is greater than that of a similar unit in a foreign language course (Eylon & Linn, 1988). Alternatively, educators must find ways to teach the "big picture" or the concept as it relates to other concepts, instead of focusing on vocabulary lists.

To focus on the big picture, students need to acquire a deeply integrated understanding of what they are being taught (Reif, 1990). This philosophy is described as "constructivism". Constructivist theorists argue that learners link new learning to prior knowledge as a means of making knowledge meaningful for them (Bruner, 1986, West & Pines, 1985).

Deep understanding, not imitative behaviors should therefore be the goal of science education. Teachers should be looking for what their students can generate, demonstrate and exhibit, not what the students can repeat. The goal of science education should be to help learners to internalize and reshape, or transform new information. Learners should not be viewed as passive but should be viewed as purposive and active learners who are ultimately responsible for their own learning. Knowledge is not 'out there' but is personally and socially constructed, and the learner should evaluate the knowledge in terms of the extent to which it fits with his/her experience. Use of analogies during science instruction can facilitate the creation of new understandings.

Statement of the Problem

Alternative Conceptions

The knowledge constructed by individuals is an attempt to organize experiences and observations so that they make sense and so that they can be used to make predictions. Students have been constructing knowledge for many years before they reach school. For example, if a typical eighth grader is asked to predict what will happen when a ball is thrown vertically up in the air, s/he would probably state that the ball will go up to some maximum height, turn around, and return to the place from which it was thrown. This kind of correct prediction from our constructed knowledge lets us function quite adequately on a day-to-day basis

Along with the constructed knowledge about a ball thrown up in the air, we have also, during the course of our lives, constructed our own private understanding of concepts such as speed, velocity, acceleration and force-concepts that have very specific meanings to scientists but that often have different meanings in our daily lives. This "private understanding" that individuals possess prior to receiving any formal scientific instruction is usually fragmented, incomplete and fraught with preconceptions, which are beliefs about the meaning and application of concepts within scientific settings (diSessa, 1988; Driver, 1990; West & Pines, 1985). When preconceptions are in conflict with scientific concepts, which is a very common occurrence for individuals who have not received prior instruction in science, they are called alternative conceptions. (Other terms used in the literature for alternative conceptions are "naive theories" and "misconceptions").

For example, if prior to taking physics an eighth grader was asked to discuss the thrown ball in terms of its acceleration, it is very likely that she would state that the ball would have a large acceleration just after it was released, that the acceleration would diminish as the ball ascends, becoming zero at the very top of the flight, and that the acceleration would again increase as the ball descends. This alternative conception, in which acceleration is treated as if it were equivalent to speed, is very common (Clement, 1972; Mestre, 1994).

Alternative conceptions are common across the sciences (Champagne, Klopfer & Gunstone, 1982). One study in biology investigated students' understanding of how plants made food (Wandersee, 1987). The study, conducted with students from grades 5,8 and 11, as well as college sophomores, probed students' understanding of the role of soil in plant growth, of the role of photosynthesis, and the primary source of food in green plants. Although students in the higher grades displayed more correct understanding, students from all grade levels displayed alternative conceptions. These included: the soil loses weight as plants grow in it, the soil is the plant's food, roots absorb soil, plants convert energy from the sun directly into matter, plants give off mainly carbon dioxide, chlorophyll is the plant's blood, and chlorophyll is not available in the air in autumn and winter so the leaf cannot get food.

Research findings consistently show that alternative conceptions are deeply seated and likely to remain after instruction, or even resurface some weeks after students have displayed some initial understanding immediately following instruction (Clement, 1982). One of the reasons that these alternative conceptions are deeply seated is that students have spent considerable time and energy constructing their naive theories. They have an emotional and intellectual attachment to them. Students cling to their erroneous beliefs tenaciously, often explaining away conflicts between scientific concepts and their naive theories by reinterpreting the lessons taught by teachers or by making inconsequential modifications to their theories. An examples of this comes from a study of children's understanding of the earth's shape (Vosinadou,1989). Children who believe that the earth is square and are then told that it is round, picture the earth as round like a pancake, not round like a sphere. If they are then told that it is round like a sphere, these children incorporate the new information about a spherical earth within their flat-earth view by picturing a pancake-like flat surface inside or on top of a sphere, with humans standing on top of the pancake.

What is deceptive is that students often display "understanding" in standardized science tests, and in the tests constructed by teachers or provided by commercial textbooks, thereby giving teachers a false sense of their students' true understanding. Tests that probe for factual knowledge or that do not force students to apply the concepts covered in class in a wide range of situations will continue to show that students "understand" the material covered in class. Clearly, children see things differently than adults in the same way that novices see things differently than experts. Since adults and experts have fewer alternative conceptions than children and novices, one should attempt to understand those differences to make learning more efficient and meaningful. In constructing a possible instructional recipe for imparting scientific concepts, we should consider not only the alternative conceptions that different ability groups hold, but the organization and use of the knowledge that is responsible for these alternative conceptions.

Background

Expertise/ Novice. Research comparing expert and novice performance offer insight into how one might go about making the transition from novice to expert more efficient. Findings from expert-novice studies are often discussed within two categories: knowledge organization and knowledge use. Research findings suggest that experts and novices organize their knowledge in memory rather differently. Currently, it is believed that experts organize their knowledge into clusters of related knowledge referred to as "chunks," with the various pieces of knowledge in a chunk governed by an underlying concept. The chunks, are similar to a pyramid, with the most fundamental concepts occupying the higher levels of the hierarchy, followed by the ancillary concepts, and with the factual information stored at the lowest level (Glaser, 1992, Mestre, 1994). Within this model of knowledge, "knowing more" means having: 1) more conceptual chunks in memory, 2) more relations or features defining each chunk, 3) more interrelations among the chunks, and 4) effective methods for retrieving related chunks (Chi & Glaser, 1981).

There is also evidence that the hierarchical knowledge structure possessed by experts facilitates their ability to learn new related knowledge. For example, children who are experts on spiders are able to understand and recall the features of a passage on spiders after reading it, whereas children who are not knowledgeable about spiders cannot (Anderson, 1989). Basically, the more one knows about a subject the easier it is to acquire additional knowledge about the subject. To use an analogy, having a highly organized filing system, with each filing cabinet labeled by a main theme, each drawer labeled with a sub-theme, and each folder within each drawer clearly denoting specific sub-sub-themes, makes it easy to store and retrieve large amounts of information. On the other hand, a filing system where large numbers of folders containing sub-sub-themes are strewn on top of a desk make it a highly inefficient information storage-retrieval system (Gentner, 1989).

Major differences between experts and novices also emerge from investigations of how they use their knowledge to solve problems. One clear difference between the problem solving behavior of skilled and unskilled problem solvers lies in what problem attributes they cue on while deciding on a strategy for solving a problem. More specifically, shortly after reading a problem, skilled problem solvers cue on the underlying principle(s) or concept(s) that could be applied to solve it (Chi, 1981). In contrast, unskilled problem solvers cue on the objects and terminology used in problems as away of deciding on a method of attack. For example, skilled problem solvers in physics decide that two problems would be solved with a similar strategy if the same principle (i.e., Newton's Second Law) applies to both problems; in contrast, unskilled problem solvers base their decisions on whether the two problems share the same surface characteristics (i.e., both problems contain inclined planes, or pulleys and strings). Cueing on the surface characteristics of problems is not very useful since two problems that share the same objects and therefore "look" very similar may be solved by entirely different approaches (Chi, 1981).

Understanding these differences between experts and novices may help us to better understand the learning process. The prior knowledge that is responsible for the learner's alternative conceptions needs to be addressed before any meaningful learning can take place. To use an analogy, if one doesn't consider the student's prior knowledge, it is like building a house on sand rather than building the house on rock. The sand foundation shifts and is unpredictable; whereas the rock foundation is solid and permanent. A paradigm that considers the role of the student's prior knowledge as an integral part of learning is constructivism.

Constructivism. Many current proposals for science reform are based on a "constructivist" theory of knowing. Constructivism, which has its roots in Piaget, takes the point of view that individuals actively construct the knowledge they possess. This construction of knowledge is a life-long, effortful process requiring significant mental engagement by the learner. Further, the knowledge that we already possess affects our ability to learn new knowledge. If new knowledge that we are trying to learn conflicts with previously constructed knowledge, then the new knowledge will not make sense to use, and may be constructed in a way that is not useful for long-term recall or for application in a variety of situations (Anderson, 1989; Resnick, 1987).

Constructivism has important ramifications for learning and instruction in terms of constructing and reorganizing knowledge. In the constructivist view, the learner's mind is not a blank slate upon which new knowledge can be inscribed. Knowledge previously constructed by the learner will affect how s/he interprets the knowledge that the teacher is attempting to impart. Learners are not sponges ready to absorb the knowledge transmitted by the teacher in ready-to-use form. From the perspective of instruction, a constructivist teacher needs to probe the knowledge that learners have previously constructed and evaluate whether this knowledge conflicts with the knowledge being taught, otherwise there is no guarantee that learners will accommodate the new knowledge in a way that is compatible with current scientific thought. An instructional tool that accommodates the student's prior knowledge is theuse of analogical reasoning.

Analogies. Analogies are an instructional tool that forces one to reexamine the link between new knowledge and old knowledge. An analogy, according to Webster's Dictionary, is a "similarity in some respects between things otherwise unalike; a partial resemblance; and explaining something by comparing it point by point with something similar." Analogies and similes are commonly used as part of the English language, for example, one refers to the "point" of a joke as well as to the "point" of a needle.

In discussing analogical ability, the terms "base" and "target" are commonly used. These terms are used interchangeably in the field, but for the purposes of this review, "base" will refer to prior knowledge in a content area of the analogy and "target" will refer to the scientific concept that is being taught (Gentner, 1989). Analogical learning can be broken down into the sub processes of (a) accessing the base system; (b) performing the mapping between the base and target (c) evaluating the match; and (d) storing inferences in the target domain (Clement, 1982; Gentner, 1989).

Analogy use as an instructional tool has had some proven success. Analogy use was found to force the learner to reexamine old knowledge to meet the demands of understanding the new knowledge (Duit, 1991). Analogies are a technique to link the old knowledge to the new knowledge (Harrison & Treagust, 1993). Analogies may also facilitate an understanding of the abstract by pointing to similarities between the prior knowledge of the learner. Analogies can also provide visualization of abstract ideas and provoke student interest (Duit, 1991).

In light of the effectiveness of analogies, there still exist many unanswered questions in terms of successful use of analogies in the classroom. There is a lack of agreement in the developmental ability to engage in analogical thought, the conditions under which analogies are most successful (i.e., prior knowledge,context, goals) and the type of analogy used in instruction.

The ability to engage in analogical ability has been studied extensively in understanding general cognitive ability or intelligence (Kaufman & Kaufman, 1983). In the past, analogical reasoning ability was associated with formal operational thinking; however, some claim that children as young as four-years-old can reason analogically (Vosniadou, 1989; Gentner, 1977). Vosniadou (1989) claims that it is the content and organization of the knowledge base on which analogical reasoning is applied that develops and not analogical ability. It is this development of the knowledge base that makes it easier to see the relational similarities between it and other systems to generate more productive analogies.

Conditions under which analogies were used as an effective instructional tool are unclear. Most studies on assessing the learner's analogical ability were conducted in a vacumn-like environment and the analogy problems were of the standard verbal proportional type, A:B::C:?, where the student is asked to find the answer to D. These problems were not contextually related to each other or to anything that the child had seen prior to taking these assessments. This lack of concern for children's prior knowledge about the base and target domain is a common problem in developmental research on analogical reasoning (Vosinadou, 1987). These studies were testing analogical ability independent of any content and any particular goal. These studies were assessing analogical ability for analogy sake. diSessa (1990) also claims that if the learner were given analogies in a content area from which they have expertise, they would experience more success. This idea is similar to the research on expertise and novice problem solving abilities. A chess player is obviously an expert in chess and is probably not an expert in chemistry; therefore, to assess a chess player's analogical ability by asking the chess player to answer chemistry analogy questions or chemistry problems is not an accurate assessment. Again, the content area or domain from which the student is being assessed is an important consideration in assessing that student's ability.

In addition, most of the studies on analogy use as an instructional tool have been empirical studies on analogies that were created by the teacher and given to the student. In the teacher-generated analogy studies, the teachers generally drew on experiences that were familiar to the teacher, to create their analogies. The students who found this method useful were the students that had similar experiences as the teacher's analogy. Limitations of these studies were that they did not consider the student's prior knowledge, they were not current research studies, and they did not consider having the student generate their own analogy.

Summary. We need instructional tools that probe for deep conceptual understanding where the students' alternative conceptions are addressed, so the mental engagement necessary for students to reconstruct their knowledge is present. If instructors don't pay attention to this prior knowledge, learning can result in obtaining inert or ritual knowledge. Progressive knowledge reorganization hopefully moves the student's knowledge and reasoning skills to resemble those of the experts in the field. Analogies seem to be an effective tool to assist in this reorganization of knowledge by creating more conceptual chunks and relationships between the chunks, similar to experts. The use of analogies in a content area that is familiar to the student, with a specific goal, and that are generated by the students should be more effective in reorganizing knowledge for the learner than traditional instructional methods.

There is some tension between traditional practices in science and constructivist practice in science. This research examined whether the use of analogies could help bridge the gap between the two paradigms. The effect of analogies and traditional instruction in facilitating knowledge acquisition in the science classroom was examined in this research study. The effect of prior knowledge, student ability (expert/novice differences) and the effectiveness of three instructional methods (traditional science instruction, teacher-generated analogies and student-generated analogies) in a junior high science classroom were examined. The research questions were:

Research Questions

The purpose of this research is twofold:

1. Are teacher and student-generated analogies more effective than traditional instruction in bringing about change in student understanding of a given scientific concept?

2. What is the nature of the change?

    a. How are student-generated and teacher-generated analogies related to the student's subject-matter knowledge?

    b. How do the sub processes of analogical reasoning in expert and novice science students compare?

Definition of terms

Abstraction- a relationship between two domains that shares few attributes and many relations (i.e. heat flow is through a variable).

Analogy- a relation between parts of the structures of two domains. A statement of comparison on the basis of similarities between the structures of two domains (i.e., heat is like water).

Anomaly- a relationship between two domains that share few attributes and few relations (i.e., coffee is like the solar system).

Attributes- surface features that are mapped from a base to a target, usually represent shape, color, size.

Base Domain- the relational information that already exists in memory (prior knowledge).

Constructivism- a theory of knowing that involves individuals actively constructing the knowledge they possess through linking the new knowledge to prior knowledge.

Domain-Specific Knowledge- the factual and procedural information that one possesses in a particular content area.

Expert- one who possesses the availability of knowledge relevant to that domain. The reliable attainment of specific goals within a specific domain.

Literal Similarity- an analogy that shares many attributes and many relations (i.e., milk is like water).

Mere Appearance- an analogy based on many attributes or surface features and few relations (i.e.,The glass tabletop gleamed like water).

Metaphor- a figure of speech in which a word or phrase is applied to an object or action that it does not literally denote in order to imply a resemblance.

Misconception- a student conception that produces a systematic pattern of errors.

Novice- one who doesn't possess the availability of knowledge relevant to a specific domain (science).

Strategic Knowledge- the processes needed carry out problem solving (i.e., means-end analysis, working forward, working backwards, analogical reasoning).

Structural Similarity- the relationship between the base and domain, usually represented by the function of the analogy.

Target Domain- the domain to be explained (scientific concept being taught).

Verbal Analogy- A:B::C:?

Chapter 2

REVIEW OF LITERATURE

This literature review will begin by focusing on an overview of cognitive research findings on learning and problem solving in science, and discuss the implications of this body of research to science instruction. Constructivism will be discussed in its relationship to the acquisition of new knowledge and the role that it plays in reorganizing the knowledge and alternative conceptions that students already possess in learning scientific concepts. The development, organization and application of knowledge in solving problems will be reviewed within the framework of the expert/novice literature. Within this framework traditional practices for teaching science will be discussed as well as the new practice of the use of analogies.

Constructivism

Constructivism stands in contrast to the more deeply rooted ways of teaching that have long typified American classrooms. Traditionally, learning has been thought to be a "mimetic" activity, a process that involves students repeating, or miming, newly presented information (Jackson, 1986) in reports or on quizzes and tests. Constructivist theory of knowing, on the other hand, helps learners to internalize and reshape, or transform, new information.

Constructivism, as a way of coming to know one's world, is supported by a long and honorable body of literature and research. There is clearly a connection between constructivism as an epistemological and philosophical image and a general view of constructivism as an educational framework.

The philosopher Emmanuel Kant, whose work bridged the 18th and 19th centuries, attempted to wed two disparate views of knowledge: the view that logical analysis of actions and objects leads to the growth of knowledge and the view that one's individual experiences generate new knowledge. Kant contended that both views have merit: analysis, by definition, occurs after the fact; sensate experiences occur before or during the event. Both are a function of one's own mental filtering system. Kant concluded that one cannot infer new relationships among objects, events, or actions unless one has a priori views through which perceptions can be organized (Brooks, 1993).

Another contributor to the idea of constructivism, is George Kelly. The essence of Kelly's ideas that each person creates for himself or herself a model of the world that enables him/her to chart a course of behavior within it. For instance, like a scientist's model, this model is subject to change over time since constructions of reality are constantly being tested and modified to allow a better working model to be created (Watts, 1990). Kelly's theory emphasizes 'anticipation'. People who anticipate events successfully have built a coherent construct system. This system can account for previous experiences, interpret present cicumstances, shape forecasts of approaching eventualities and help assess the accuracy of past predictions (Watts, 1990). Kelly stressed the uniqueness of each person's construct system.

Jean Piaget was one of the most influential proponents of constructivism. His research led him to conclude that the growth of knowledge is the result of individual constructions made by the learner. Piaget viewed constructivism as a way of explaining how people come to know about their world. He viewed the human brain as a dynamic set of cognitive structures that help us make sense of what we perceive.These structures grow in intellectual complexity as we mature and as we interact with the world we come to know and as we gain experience. Through maturation and experience, the groundwork for new structures is laid.

In Piagetian terms, the temporary cognitive stability resulting from the balance of assimilation and accomodation is called equilibrium (Piaget, 1926). This construction of knowledge is a life-long, effortful process requiring significant mental engagement by the learner. Further, the knowledge that one already possess affects our ability to learn new knowledge. If new knowledge that we are trying to learn conflicts with previously constructed knowledge, then the new knowledge will not make sense to us, and may be constructed in a way that is not useful for long-term recall or application in a variety of situations (Anderson, 1987; Resnick, 1987).

Constructivism has important controversial ramifications for learning and instruction. In the constructivist view, the learner is not a blank slate upon which new knowledge can be inscribed. Knowledge previously constructed by the learner will affect how s/he interprets the knowledge that the teacher is attempting to impart (Anderson, 1987). In short, learners are not sponges ready to absorb the knowledge transmitted by the teacher in ready-to-use form. From the perspective of instruction, a constructivist teacher needs to probe the knowledge that learners have previously constructed and evaluate how the new knowledge is related to new information being taught. If there is a relationship, the teacher, must take care to guide learners in re-constructing knowledge, otherwise there is no guarantee that learners will accommodate the new knowledge in a way that is compatible with correct scientific theory. Much of the confusion that students exhibit in learning scientific concepts might derive from conflicts between previously-constructed knowledge and the concepts they are trying to learn.

Constructivists criticize traditional instruction that relies heavily on the textbook as being teacher-dominant or "absorption" method (Grossen, Romance & Vital, 1994). The traditional teacher-dominant approach, or absorption method, presents such a barrage of ideas that students are likely to rely on strategies that emphasize rote memorization rather than rely on strategies that foster understanding (Yager, 1983).

The most frequently noted instructional problem is that of inert or ritual knowledge (Alexander, 1992). Ritual knowledge is knowledge that seems to exist but is not applied broadly or flexibly. Students often fail to solve problems, not because they lack the knowledge, but because they are unable to use their knowledge flexibly (Lochhead, 1990). Research has repeatedly documented that students who demonstrate successful learning of a principle on a daily assignment often fail to use it to solve problems on another occasion (Schoenfeld, 1987; Smith & Good, 1984). Instead of using their new knowledge, which seems to have been mastered according to classroom tests, students often revert to their inappropriate preinstructional conceptual frameworks in real-life, problem-solving situations (Tobin, Espinet, Byrd, & Adams, 1988). "Under a thin surface layer of superficially learned science knowledge, students' pre-instructional conceptual frameworks appear to be mainly unchanged by instruction" (Duit, 1991, p. 652). Using the students naive beliefs and misconceptions to help "change their minds" can be an invaluable element of the learning process, according to the constructivist paradigm.

Many biological developmental constructivists recommend presenting knowledge as a whole in naturalistic context, without the traditional use of particular textbooks and without explicit, teacher-directed instruction. Thus the instructional focus shifts from the curriculum and the teacher to the learner (Gunstone, White & Fenshaw, 1986). Support for this approach grows out of the belief that explicit presentation prevents meaningful understanding. For example, Piaget argued: "Each time one prematurely teaches a child something he could have discovered for himself, that child is kept from inventing it and consequently from understanding it completely" (Piaget, 1926, p. 115). Although this approach is a highly idealistic, this is not a realistic idea due to the design and organization of our school systems.

Alternative Conceptions in Science

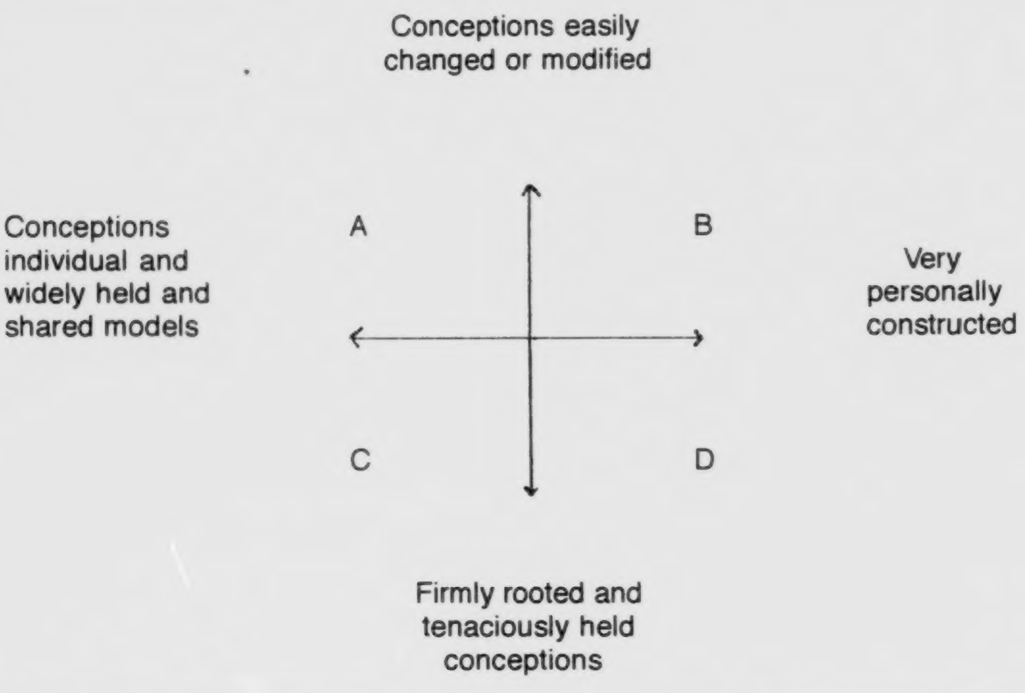
By the time students enter the classrooms, they have been constructing knowledge for many years. The knowledge constructed by individuals is an attempt to organize experiences and observations so that they make sense and so that they can be used to make predictions. For example, if a typical eighth grader is asked to predict what will happen when a ball is thrown vertically up in the air, she would probably state that the ball will go up to some maximum height, turn around, and return to the place from which it was thrown. These kinds of correct predictions from one's constructed knowledge lets one function quite adequately on a day-to-day basis.

Conceptions develop as individuals respond to the barrage of everyday influences and experiences around them. A teacher might wonder why it is difficult for students to believe that a dusty old book lying on a shelf has energy. The students would argue that energy has to do with movement, activity, liveliness or living. Most people have seen the advertisement for electricity showing a newborn baby in an incubator over the caption 'Energy for life' (Watts, 1990).

To begin to use students frameworks of ideas seriously, teachers need to understand how widespread and stubbornly rooted they are. It is not just advertising and television, but a host of everyday experiences and physical sensations which contribute to supporting intuitive and 'commonsense' ideas.

Some conceptions are shared by a large number of people, and so the probability of finding that conception present in the responses from members of a class must be high. Other conceptions are the product of particular experiences and ways of things, and so might be specific to a minority of individuals (Watts, 1990). Some conceptions are easily changed while others must be deep-seated, making them difficult to alter as shown in Table 1.

Table 1
A Conceptual Matrix


Conceptions easily changed or modified
Conceptions individual and widely held and shared models
A
B
Very personally constructed
C
D
Firmly rooted and tenaciously held conceptions

Note. From Problem Solving in Science, Watts (1990)

The placement of conceptions in this matrix should influence the teachers strategy for teaching. For example, conceptions in quadrant A could be dealt with quite quickly with the whole class. An instance might be of students who have a 'clashing current' model of electric circuits: who suggest that current comes out in opposite directions from the ends of the battery and clashes in the bulb to produce light (Watts, 1990).

Conceptions in quadrant B are more difficult to discover and would probably be apparent in discussion groups, individual answers to questions and homework. A more effective strategy would be tackle them individually. More severe are conceptions in quadrant C. These have been the subject of most of the research into conceptual change (Watts, 1990). These conceptions are deep-seated and reinforced by commonsense interpretations of events in everyday life. One possible approach to help these learners is help them develop shared models of what they think is happening, and then spend time working through them in detail.

Finally, conceptions in quadrant D are the most difficult to contend with (Watts,1990). For instance, a youngster might develop very interesting and creative models about light (Watts, 1990). Such conceptions are usually the most interesting in that they allow some window upon the ways in which conceptions develop.

The Development of Biological Knowledge

Becoming prominent with the work of Piaget in the 1920s and continuing through Von Glasserfald to the present, an enormous effort has been concentrated on understanding the ways in which learners view the natural world, and consequently, what teachers need to do to encourage conceptual change in the biological or life sciences. Learners come to formal science instruction with a diverse set of alternative conceptions concerning natural objects and events. These alternative conceptions can interfere with the learning process.

Work on children's understanding of the life science concepts spans some 60 years, from Piaget's (1926) efforts to more recent studies growing out of conceptual change theory (Carey, 1985). Piaget proposed a four-stage theory that describes the emergence of the *life* concept. Accordingly, children ascribe *life* to (1) objects exhibiting activity or usefulness (ages 3 to 7), (2) movement of any kind (ages 7 & 8), (3) spontaneous movement (ages 9 to 11) and finally (4) (at ages 11 & 12) to plants and animals.Subsequent studies produced a set of anomalous results that cast doubt on the stage theory, and efforts by Carey (1985) suggest that the acquisition of the life concept may involve a fundamental reorganization of relevant knowledge structures between the ages of 7 to 10, replacing naive psychological notions with an "intuitive biology."

The meanings that learners assign to the concepts of animal and plant have been reasonably well documented (Bell, 1981, Wandersee, 1986). It appears that learners of all ages subscribe to a highly restricted understanding of animals, applying the label almost exclusively to vertebrates. Characteristics of plants are even more poorly understood by science students. Stavy and Wax (1989) found that 57% of the 11-13 year-old Israeli children in their study considered plants to be alive, 66% thought that plants reproduce, and 88%

thought that plants must eat.

Research on students' understanding of anatomical and physiological concepts reveals that even young children have well-developed ideas about the human body (Arnaudin & Mintzes, 1985). Many children (as young as 10 years) depict a vast array of internal structures when asked to draw the inside of their body. A large proportion of students at all levels seems to believe that a separate system of tubes carries air to the heart and other body structures.

The structure of cells and cellular phenomena, including cell division, protein synthesis, respiration, and photosynthesis have received growing attention (Anderson, 1987; Stavy, 1988; Wandersee, 1985). The notion that green plants synthesize their own food intracellularly seems to pose an almost insurmountable problem for many students. When asked about plant nutrition, a large proportion of individuals, including those who have taken several previous biology courses, insist that plants obtain food from the soil. Learners come to science classes with a multitude of alternative conceptions or preconceptions of which the instructor must work with in order to create successful conceptual change.

Researchers show that misconceptions are deeply seated and likely to remain after instruction, or even resurface some weeks after students have displayed some initial understanding immediately following instruction (Clement, 1982). Because students have spent considerable time and energy constructing their naive theories, the students have an emotional and intellectual attachment to them. Students cling to their erroneous beliefs tenaciously, often explaining away conflicts between scientific concepts and their naive theories by reinterpreting the lessons taught by teachers or by making inconsequential modifications to their theories (Mestre, 1994). A clear example of this phenomenon comes from a study of children's understanding of the earth's shape (Vosniadou & Brewer, as reported in Chi, in press).

What is deceptive is that students often display "understanding" in standardized science tests, and in the tests constructed by teachers or provided by commercial textbooks, thereby giving teachers a false sense of their students' true understanding. Tests that probe for factual knowledge or that do not force students to apply the concepts covered in class in a wide range of situations will continue to show that students "understand" the material covered in class. An important point is that context makes a difference. Naive theories have worked well in everyday contexts, so why should they change? What is clear is that without some catalyst, such as tests that probe for deep conceptual understanding, the use of analogies, or classroom discussions where misconceptions are addressed, the mental engagement necessary for students to re-construct their knowledge will remain absent.

Organization of Knowledge

Problem solving is ubiquitous in the sciences. To understand why it is so difficult for students to develop problem-solving skills, it is necessary to examine the following ingredients necessary to be "proficient" at solving problems : 1) an understanding of the biological principle or concept, or the domain knowledge 2) ability to recognize which principles/concepts apply to problems varying widely in context,and 3) knowledge of procedures for applying the principles/ concepts, or the strategic knowledge. Being a proficient problem solver requires not only multiple proficiencies in these "higher-order" skills, but also a sophisticated memory management scheme.

To study such a complex process as problem solving, researchers have focused on investigating the performance of those who are proficient problem solvers, or experts, and those who are beginners but aspiring to become proficient problem solvers, or novices. Hopefully, by comparing the performance of experts to that of novices, insights will emerge on the behavior of experts. Expert-novice problem-solving studies have ranged across a wide variety of domains. Research in cognitive psychology during the past two decades has two findings about academic performance. First, those who know more about a particular domain generally understand and remember better than those with only limited knowledge. Second, those who monitor and regulate their cognitive processing appropriately during task performance do better than those who do not engage in such strategic processing. There is an abundance of convincing literature for both arguments of domain and strategic knowledge.

Domain-Specific Knowledge

"We cannot produce physicists without teaching physics"

Various interpretations of the terms domain-specific and strategic knowledge now exist in the literature. For the purposes of this review, domain-specific knowledge will be the declarative, procedural, or conditional knowledge one possess relative to a particular field of study. Declarative knowledge refers to the factual information (knowing what), whereas procedural knowledge is the compilation of declarative knowledge that incorporates domain-specific strategies (knowing how). Conditional knowledge entails the understanding of when and where to access certain facts or employ particular procedures (Alexander & Judy, 1988).

In many of the expert/novice studies analyzed the terminology was often conceptually confusing. One possible definition is that expert performance involves “the reliable attainment of specific goals within a specific domain.” A more demanding definition is that “an expert is someone who can make an appropriate response to a situation that contains a degree of unpredictability.” For the purposes of this review, experts possess a domain-specific knowledge base that is both extensive and accessible.

A foundation of domain-specific knowledge seems requisite to the efficient and effective utilization of strategic knowledge (Alexander & Judy, l988). Simon (1980) examined the role of content knowledge in the development of competence and stated “we cannot produce physicists without teaching physics.” In the opinion of Simon and others who have compared the performance of experts to that of novices, there can be no such thing as expertise without a knowledge base that is both extensive and accessible (Chi, 1981; 1985).

Newell (1980) and Resnick (1987) claim that a certain amount of domain knowledge is necessary for the efficient and effective utilization of strategic knowledge. Piaget also states that one must have a prior mental structure in order to "assimilate" experience correctly. Before a learner can apply strategic knowledge to a domain task in a manner that will facilitate completion, the learner must possess some knowledge relevant to that domain. In their examination of experts' and novices' problem solving in genetics, Smith and Good (1984) also concluded that the availability of relevant and appropriate content distinguished successful from unsuccessful problem solvers. They further resolved that although a certain body of relevant genetics knowledge was prerequisite to task completion, additional knowledge increased the efficiency and ease of problem solving.

Effects of Training. Alexander & Judy (1990) provide further evidence of the foundational role played by domain knowledge. They found that sixth graders who were low in knowledge of human biology benefited little from explicit instruction in the general strategy of analogical reasoning. They concluded that without basic competence in the domain, the training of this general strategy was not feasible. This conclusion was also supported by several other training studies (Klahr & Carver, 1987; Schoenfeld, 1987; Alexander & Judy, 1988).

Effects of Incomplete Knowledge. These studies contend that although a base of domain knowledge may be required for strategic performance, inaccurate or incomplete knowledge may work to the detriment of the learning process. Under certain circumstances, it is conceivable that one's domain knowledge may actually interfere with rather than facilitate learning (Pressley & Johnson, 1989). The "scientists" view compared to the naive idea illustrate why incomplete knowledge may impede the learning process. Alvermann,Smith, and Readence (1987) discovered that when sixth graders were asked to remember all they knew about a science topic before reading a related passage this activation of background knowledge hindered text comprehension. The impact of learners' misconceptions is well documented in physics. Smith & diSessa (1993) found a degree of uniformity in the inaccurate ideas of a more knowledgeable adult and naive children. He found that a successful physics student who could demonstrate an extensive understanding of Newtonian principles in a classroom setting was unable to transfer that understanding to a less school-like task. If the teacher can make the "scientists" idea intelligent and sensible through the use of analogies, then hopefully, the students would choose it over their initial preconceptions. This is why students need to make their ideas explicit so that they can see why their ideas sometimes don't work.

Conceptual change in middle school science students was investigated by Roth (1985). When Roth attempted to trace middle-school students' thinking as they studied a chapter on photosynthesis, she discovered that poorer readers held their world knowledge and book knowledge separate. What she determined was that these poorer readers had a tendency to overrely on either their background knowledge or the text. Again, some of these misconceptions are difficult to change and the context of use is important. A consideration of their prior knowledge in photosynthesis would be interesting.

Expertise and Problem Recognition. Experts excel in a specific domain. There is little evidence that a person highly skilled in one domain can transfer the skill to another, for instance chess players and computer programmers. As Minsky and Papert (1974) noted: "A very intelligent person might be that way because of specific local features of his knowledge-organizing knowledge rather than because of global qualities of his 'thinking'. Evidence for such a conclusion can be drawn from the work of Voss & Post (1983) on problem solving in political science. In that work, nondomain experts (chemists) solved political science problems much like novices, describing the causes for the problem at a very concrete and specific level, whereas domain experts described more abstract casual categories. The organization of knowledge specific to the domain seems to beimportant in distinguishing experts and novices.

The obvious reason for excellence of experts is that they have a good deal of domain knowledge and experience (Ericsson & Charness, 1994). This is easily demonstrated; for example, in medical diagnosis, expert physicians differentiate common diseases into more disease variants (Johnson et al., 1981). Likewise, in examining taxi drivers' knowledge of routes, Chase (1983) found that expert drivers can generate a far greater number of secondary routes (i.e., lesser known streets) than novice drivers.

Experts also perceive large meaningful patterns in their domain. This is apparent in chess, where it is well known that chess masters excel in their recall of the clusters of pieces that they see. This perceptual superiority has been replicated in several other domains, in reading circuit diagrams (Egan & Schwartz, 1979), in reading architectural plans (Akin, 1980), and in interpreting x-rays plates (Lesgold, 1988). This ability to see meaningful patterns does not reflect a generally superior perceptual ability; rather, it reflects an organization of the knowledge base. Programmers, for example, can recall key programming language words in meaningful clusters (McKeithen, Reitman, Reuter, & Hirtle, 1981), and expert programmers can also recognize and recall familiar subroutines. Experts see and represent a problem in their domain at a deeper (more principled) level than novices; novices tend to represent a problem at a superficial level.

A way to demonstrate this is to ask experts and novices to sort problems and analyze the nature of their groupings. Using physics problems, Chi, Feltovich, and Glaser (1981) found that experts used principles of mechanics to organize categories, whereas novice built their problem categories around literal objects stated in the problem description. Similar results have been found in the domain of programming; when expert and novice programmers were asked to programming problems, the experts sorted them according to solution algorithms, whereas thenovices sorted them according to areas of application (e.g., whether the program was supposed to create a list of employees' salaries or whether it was supposed to keep a file of current user identifications). These results indicate that both experts and novices have conceptual categories, but that the experts' categories are semantically or principle-based, whereas the categories of the novices are syntactically or surface-feature oriented. However, according to Smith, diSessa & Rochelle (1993) this could also depend on the context of application.

Smith et al. (1993) argues that the intuitive ideas of physics novices contain both a sense of surface structure and a sense of deep structure. She claims that novices are asked to perform under conditions in which they are incompetent, and the questions they answer are inappropriate measures of their real competence. They state that novices are characterized as concrete, conceiving only the directly perceivable aspects of situations. Smith & diSessa's (1993) alternative position is that novices possess many abstract thinking elements intuitively, which are similar to those of experts. In short, in a situation like plucking a spoke to find out if it is under tension, a novice's intuitive explanation of the phenomena is abstract in the same sense that expert knowledge is abstract. Novices appear to think concretely when they have been asked to classify problems that they are unable to solve and have nothing but generic, noncausal descriptions to rely on. Experts are classified as abstract because they have the particular abstractions selected as relevant- those that happen to solve the problems posed in research studies.

Owen and Sweller's (1985) description of novices' greater reliance upon less efficient strategies, such as means-end analysis, has been documented by others (Pressley & Johnson, 1989; Voss & Post, 1983). In the Gay (1986) study, strategic processing differences between students with low and high conceptual knowledge of protein synthesis were manifested. As has been shown in the good/poor reader and the expert/novice literature, the students low in conceptual knowledge frequently lacked strategic maturity. They had problems (a) realizing when they understood, (b) determining the amount of practice they required, and (c) deciding what strategies would be most appropriate. Furthermore, these low conceptual learners, like the poorer students in the Chi (1981) study, used examples to extend what they knew rather than to explore what they did not know. The pattern for students identified as high in conceptual knowledge was quite different, however. These students used self-questioning to identify their areas of weakness and organized and reflected upon their performance throughout their problem solving.

In summary, the expert/novice literature in terms of domain knowledge is characterized by the organization of their knowledge. Experts tend to be domain specific which suggests a lot of knowledge in the specific domain. Experts also perceive large meaningful patterns in their domain which reflects a different organization of the knowledge base. Also, experts represent a problem at a deeper level based on principles rather than on surface features, like novices. However, Smith & diSessa (1993) argue that novices can reason like experts if the novices are working within a familiar domain, one in which they are more "expert-like".

Strategic Knowledge

" Bare facts don't solve problems"

"Bare facts don't solve problems" claims Simon (1980). The advocates of this view state that strategic knowledge contributes to the utilization and acquisition of domain-specific knowledge. There is a lot of research with cases where individuals who apparently possessed the requisite knowledge remained unsuccessful at task performance (Schoenfeld, 1987; Smith & Good, 1984). One explanation for this continued failure in the face of an adequate body of content knowledge is that these individuals may lack the strategic processes that activate or operate upon that body of knowledge or it may be a lack of conditional knowledge, which is a form of domain knowledge. Strategic knowledge is usually characterized as strategies such as working forward, working backward, means-end analysis logical reasoning and analogical reasoning.

Without a rich repertoire of strategic knowledge upon which to draw, a learner may persist in the accumulation of inert knowledge (Bransford,Sherwood, Vye & Reiser, 1986); that is, knowledge accessed in only routinized contexts. Pressley & Johnson (1988) believe that students should be taught to engage in elaborative interrogation during learning. Specifically, they should be instructed to question themselves about the importance of the knowledge to be learned and they should monitor why specific factual relations exist.

One of the strategic differences that apparently emerges from increased knowledge relates to problem representation. The differential representation of problems has been reported across many tasks and domains. When experts and novices in the area of political science were asked to address a question about agricultural problems in the Soviet Union, several contrasts in their organization of the problem were evidenced (Voss et al., 1983). During the initial phases of problem solving, experts reviewed the task for much more time than the novices. By comparison, the novices broke the problem down into smaller problems when generating a solution. This also reflects the amount of content knowledge available to them.

The importance of strategic knowledge is demonstrated in the area of estimation. The think-aloud protocols of good estimators revealed that these individuals not only possessed speed and accuracy of recall of basic mathematical facts, but also showed great flexibility in their initial selection of the most appropriate estimation strategies from a cadre of strategies (Reys, Rybolt, Bestgen, & Wyatt, 1982).That is, good estimators can be characterized as planful and flexible in their strategy use.

The failure of learners to make use of their available resources was illustrated in two recent studies involving the transmission of science content to fifth graders. In the Reys et al. (1982) study, the successful fifth graders were nonselective in their use of available resources. These successful students comprehended the unfamiliar science content and were able to apply that content in a summarization task. These learners' strategic approach to the task facilitated their learning.

The Chi et al. (1981) investigation on learning from examples highlights this role of strategic knowledge in the acquisition of domain knowledge. By analyzing novices college students' think-aloud protocols as they studied worked-out examples of mechanics problems, they surmised that students who performed better employed strategies that enabled them to gain more information from the example than poorer students. The poorer students detected relatively few problems in the understanding and used the worked-out examples primarily to reinforce what they already knew. The better students, by contrast, were more cognizant of their comprehension failures, attended more to different examples, and concentrated more effort in those areas where they lacked understanding. Thus, the more effective learners were able to extract more content information from the instructional opportunity than the less effective learners.

Another characteristic of problem representation that Voss et. al. (1983) noted was the tendency of experts to establish a context for the task prior to engaging in solution. Another characteristic of the more knowledgeable individuals is their tendency to classify or categorize problems on the basis of underlying principles or concepts. Siegel, Goldmith & Madson (1983) discovered that in working estimation problems, younger children depended on perceptually based strategies in nearly two thirds of their solutions. In contrast, the older children that they studied reverted to these surface-level strategies only when confronted with more difficult or complex problems. Again, it is important to recognize the importance of the context in the application of this knowledge.

Effects of Training. It seems as though the better students in the Chi et al. (1981) study came to the cognitive task (novice college students' think-aloud protocols to solve mechanics problems) having already acquired valuable strategic knowledge. Instructional programs that emphasize strategic processing can facilitate the acquisition of strategic knowledge. In one such program, college students enrolled in an introductory physics course were able to acquire information independently from text after being taught a general learning strategy for understanding relations in physics (Larkin & Reif, 1976).

Expertise and Memory. Experts demonstrate superior performance on short-term and long-term tasks. With recently presented materials, experts' recall seems to exceed the limits of short-term memory. This is not because their short-term memory is larger than other humans', but because the automaticity of many portions of their skills frees up resources for greater storage. Experts seem to excel in long-term recall as well.

Chase and Ericsson's (1982) study demonstrated experts' superiority in both short-term and long-term recall. They found that their trained memory expert could remember more than 80 digits in a short-term memory serial recall task. They also found, however, that he could recognize over 80-90% of the digit groups that had been presented to him for recall a week earlier. They found that the experts were able to "chunk" more digits together allowing them to remember the digits.

Experts spend a great deal of time analyzing a problem qualitatively. Protocols show that, at the beginning of a problem-solving episode, experts typically try to "understand" a problem, whereas novices plunge immediately into attempting to apply equations and to solve for an unknown. Basically the experts build a mental representation from which they can infer relations that can define the situation, and they add constraints to the problem. Paige and Simon's (1966) example illustrates this by asking students to solve simple algebra word problems, such as: A board was sawed into two pieces. One piece was two thirds as long as the whole board and was exceeded in length by the second piece by four feet. How long was the board before it was cut? Paige et al. (1966) found that some students immediately applied equations, which then resulted in their coming up with a negative length; others' however, remarked that the problem was meaningless because one cannot have a board with a negative length. One can conclude that those students who paused had formed a mental model of the situation and made some inferences about the relations between the boards.

Expertise Knowledge Organization. Findings from expert-novice studies are often discussed within two categories: knowledge organization and knowledge use. Research findings suggest that experts and novices organized their knowledge in memory rather differently. Currently it is believed that experts organize their knowledge into clusters of related knowledge referred to as "chunks," with the various pieces of knowledge in a chunk governed by an underlying principle or concept. The chunks , in turn, can be envisioned as comprising a richly interconnected hierarchical network, with the most fundamental principles/concepts occupying the higher levels of the hierarchy, followed by ancillary concepts, and with factual/mathematical information stored at the lowest levels (Larkin & Reif,1976; Mestre, 1994). Egan & Schwartz (1979) have demonstrated the current perception of experts' knowledge organization. In this experiment, expert and novice electronic technicians were shown a complex circuit diagram for a very short time and then asked to reproduce as much of the diagram from memory as they could. The experts could reproduce accurately much of the circuit diagram following exposures of only a few seconds, whereas novices could not. The experts were capable of such remarkable recall by chunking several individual circuit elements (e.g., resistors) that performed an underlying function in the circuit.

There is also evidence that the hierarchical knowledge structure possessed by experts facilitates their ability to learn new related knowledge. For example, children who are experts on spiders are able to understand and recall the salient features of a passage on spiders after reading it, whereas children who are not knowledgeable about spiders cannot (Anderson & Smith, 1986). In short, the more one knows about a subject the easier it is to acquire additional knowledge about the subject. To use an analogy, having a highly organized filing system, with each filing cabinet labeled by a main theme, each drawer labeled with a sub-theme, and each folder within each drawer clearly denoting specific sub-sub-themes, makes it easy to store and retrieve large amounts of information. On the other hand, a filing system where large numbers of folders containing sub-sub-themes are strewn on top of a desk make a highly inefficient information storage-retreival system (Mestre,1994).

Expertise Use of Strategies. Major differences between experts and novices also emerge from investigations of how they use their knowledge to solve problems. One clear difference between the problem solving behavior of skilled and unskilled problem solvers lies in what problem attributes they cue on while deciding on a strategy for solving a problem. More specifically shortly after reading a problem, skilled problem solvers cue on the underlying principle(s) or concept (s) that could be applied to solve it (Chi et al., 1981). In contrast, unskilled problem solvers cue on the objects and terminology used in problems as a way of deciding on a method of attack. For example, skilled problem solvers in physics decide that two problems would be solved with a similar strategy if the same principle applies to both problems ; in contrast, unskilled problem solvers base their decisions on whether the two problems share the same surface characteristics (e.g., both problems contain inclined planes, or pulleys and strings). Cueing on the surface characteristics of problems is not very useful since two problems that share the same objects and therefore “look” very similar may be solved by entirely different approaches.

Expert-novice differences in knowledge use also emerge from observing the actions of individuals actively engaged in solving problems. After deciding on the concept (s) that apply to a problem, skilled problem solvers next decide on a procedure by which the concept (s) can be applied, and then, in quantitative domains, apply the relevant formulas to generate answers. On the other hand, unskilled problem solvers resort to finding and manipulating equations that contain the quantities given in the problem until they isolate the quantity or variable being asked for (Chi et al., 1981; Larkin & Reif, 1976; Mestre,1994).

In summary, it is the tendency of skilled problem solvers to conduct qualitative analyses of problems prior to executing the quantitative solution that distinguishes them from unskilled problem solvers. Knowledge (representation) and problem solving (strategic) literatures really blend. Some research can be used to make different points. It seems to be a matter of definition. Generally researchers are starting to view knowledge as a more dynamic process. Hence, strategies can really be thought of as part of one’s domain knowledge or "conditionalized knowledge".

Do current teaching practices in science education reflect our best understanding of how students learn and of how skilled problem solvers solve problems? This question is addressed from the perspective of how science is taught in traditional curriculums in grades 1-12.

Practices of Teaching Science

Traditional approaches

Traditional approaches of teaching science consist of presenting material through lectures while students sit quietly "learning" it, reading chapters from textbooks, simulating lab activities and triadic discussions (Mestre, 1994).This approach, termed "transmittalist instruction," assumes that students can absorb scientific knowledge while passively listening to instructors (Mestre, 1994). An assumption behind this method of instruction is that ability to understand the material being transmitted depends largely on the clarity of the presentation. If a student fails to understand, then making the presentations clearer or more insistent should make the material transparent for the student; often making a presentation clearer or more insistent translates to the teacher speaking slower and in a louder voice (Mestre, 1994). This view is inconsistent with cognitive research findings.Transmittalist instruction isn't ideal for the construction of knowledge by students.

The most commonly used teaching tool is the textbook which controls 70% of the instructional activity in science (Raisen, 1988). Many criticisms have been made of science texts. Among others, they contain too many vocabulary terms, present ideas in a list, are unclear and generally unable to affect conceptual change (Anderson & Smith, 1986). In addition to being excessive in number, these vocabulary terms are rarely reviewed and connected in relevant ways. Most phenomena are explained in terms of what happens first, second, and so on. These phenomena are rarely explained in terms of underlying forces and principles. For example, the life and death of stars is described in terms of the stages. The underlying causes for their appearance and disappearance is not described at all. Other phenomena are rarely explained in terms of underlying forces and principles. Textbooks don't have to be bad, publishers just need to consider cognitive learning theories with their editorial staff.

The order of introduction of concepts also is often a problem. One text introduced conduction, convection, and radiation in the book, after students had already learned about phenomena that are explained by these principles (Grossen, Romance, Vitale, 1994). This separate treatment of applications of the same principle can only serve to fragment student understanding at best, and at worst provide no understanding at all. Special instructional activities such as indicating key features, or elaborating on prior knowledge, usually were not defined by the teacher (Grossen, Romance, Vitale, 1994).

In contrast to traditional instructional strategies, constructivists suggest alternative strategies that are in direct opposition to teacher-directed approaches in education. Some constructivists advocate more studentnegotiated approaches in order to link new meaning to prior knowledge. Constructivists suggest techniques such as concept mapping, hands-on activities and logical and analogical reasoning strategies as an effective means of instruction.

Constructivist approaches

A number of specific approaches suggested by constructivists are currently popular recommendations for reform in science education. Among their suggestions are concept mapping, activity-based programs and general-strategy instruction.

Novak and Gowin (1984) developed concept-mapping to aid the identification of the misconceptions that provide a basis for planning conceptual change. This technique requires students to create maps that illustrate the links between vocabulary words as they learn. Concept-mapping is not to be equated with teacher-constructed maps, and teachers are not to inform students of how concepts are linked in science. The presentation of completed maps of information, such as in a teacher-drawn diagram or model, is thought to "confuse the student, propagate errors, or foster misconception . . . Explicit diagrams often create new learning problems instead of solving them" (Cullen, 1990, p. 106). As students construct concept maps, they are believed to construct an integrated knowledge base and link new knowledge with prior knowledge. By reviewing these maps, the teacher is to identify misconceptions and use conceptual change strategies to confront the misconceptions. In spite of the fact that there is incongruent evidence to support this, concept mapping is supported by many science teachers and publishers.

Another common recommendation is to provide students with hands-on activities where they can figure out science principles by directly experiencing, observing, and experimenting with scientific phenomena.These inquiry methods emphasize students figuring things out without the teacher telling them what or how to do it. There is a problem with this method in that to limit hands-on activities to only non-directed strategies seems to be an unwise decision. Linn and Songer (1991) concluded from their experiments with activity-based inquiry instruction that students "learn to break glassware or create bubbly mixtures, but not to relate their experiments to any scientific principle" (p. 121).

Another frequently recommended technique is to teach general strategies for problem-solving (Schoenfeld, 1989). General strategies encompass both problem-solving strategies (e.g., working forward, backward, means-end analysis) and other strategies, such as the scientific process and reasoning strategies (analogical and logical reasoning). This recommendation is based on the assumption that the reason students fail in problem solving is not because they lack the knowledge, but because they are unable to use their knowledge flexibly (Lochhead, 1990).

Teaching general problem-solving strategies, alone, (i.e., analogical reasoning) is not effective in achieving better problem-solving performance

(Bransford, 1985). It seems that strategies for problem solving, specifically, analogoical reasoning are more easily learned in the context of using one's scientific knowledge base to solve problems and enhance one's memory. The research findings are that the use of analogies may have a lot of promise in terms of teaching abstract concepts in science. Historically, analogies have been used by scientists to explain their discoveries. If the science experts used them, why aren't educators using analogies to facilitate understanding of scientific concepts? What works for the investigative scientist may be of value to other learners.

Types of Analogies

According to Webster's Dictionary a metaphor is " a figure of speech containing an implied comparison in which a word or phrase ordinarily and previously used for one thing is applied to another". An example would be "He is a lion in battle." Barker (1985) classifies metaphors into seven categories: stories, anecdotes, analogies & similes, relationship metaphors, artistic metaphors (drawings, models, paintings), objects and tasks with metaphorical meanings.

Metaphor has been an essential feature of communication in teaching. Anecdotes have long been used to convey specific messages. The earliest recorded stories can be found in the Bible. Greek mythology abounds with stories that are rich in symbolic meaning; the tale of Daedalus and Icarus is a good example. Apart from what it says about father-son and ruler-subject relationships, it teaches the virtues of careful observation and diligent practice and the dangers of overconfidence (Lakoff & Johnson, 1980).

Fairy tales and stories are important to most societies. Such narrative accounts tell listeners or readers about the human condition in particularly graphic ways. Long before the neglect, abuse, and exploitation of children came the subject of general discussion and debate, for example, the story of Cinderella and the message about the mistreatment of stepchildren (Barker, 1985). Even the simple sad tale of Humpty Dumpty carries its message: Be careful what you do because sometimes even the experts can't repair the damage resulting from ill-judged acts (Lakoff & Johnson, 1980).

One type of metaphor is an analogy, Webster's Dictionary defines an analogy as a "similarity in some respects between things otherwise unalike; a partial resemblance; and explaining something by comparing it point by point with something similar." Analogies and similes are commonly used as part of the English language. One refers to the "point" of a joke as well as to the "point" of a needle, and one speaks of "riding high" when one does not refer to the process of riding a horse or anything else. There are generally three broad types of analogies used in education that consist of finding the relationship between four items : A:B::C:D.

An analogy is a verbal proportion presented in the following form: A:B::C:D. The first step in solving an analogy problem is to find a relationship between two of the three given terms. There are two techniques that may be employed to determine the nature of the relationship between the terms in a verbal analogy- one using sentences and one using categories (Bader & Burt, 1985). With the sentence technique, one begins by making up a short, simple sentence using the two terms one is considering. Then one substitutes the other given term, together with each of the answer choices, in the sentence created. One should find one combination that exactly parallels the relationship expressed by the original word pair. An analysis of the following sample question illustrates the Sentence Technique for solving analogy problems:

PLAY : AUDIENCE : : BOOK : (A. writer, B. publisher, C. plot, D. reader)

Step 1. Make a short sentence using the first two terms: (A play is meant to entertain an audience).
Step 2: Substitute the third term and each of the answer choices in the same sentence.

The second technique is the Category Technique for classifying analogies involves devising a list of common relationships between words. Through careful analysis of thousands of analogy questions, Bader & Burt (1985) has been able to distinguish eighteen categories to serve as guidelines for analogical thinking. The following categories are common in analogy tests: synonyms or similar concepts, antonyms or contrasting concepts, cause and effect, part to whole, part to part, purpose or use, action to object,object to action, place, association, sequence or time, characteristic or description, degree, measurement, grammatical, mathematical, worker to tool, and nonsemantic as described in Table 2.

Most of the developmental studies have examined this ability using

Table 2
Miller's Analogy Categories

Category of Analogy	Example of Analogy
Synonyms or similar concepts	Deliverance: Rescue::Exercise: Practice
Antonyms or contrast	Hostile: Amicable::Chase: Lewd
Cause and Effect	Heredity: Environment:: Hemophilia: Rubella
Part to whole	Leaf: Tree:: Key: Typewriter
Purpose or use	Glove: Ball:: Hook: Fish
Action to object	Pitch: Fore:: Fire: Gun
Object to action	Sprain: Swell:: Bite: Itch
Place	Paraguay: Bolivia:: Switzerland: Czechoslovakia
Association	Mozart: Music:: Pei: Architecture
Sequence or time	Sail: Steam:: Propeller: Jet
Characteristic or description	Scream: Piercing:: Cry: Plaintive
Degree	Warm: Hot:: Bright: Genius
Measurement	Odometer: Distance:: Clock: Time
Grammatical	Broke: Broken:: Flew: Flown
Mathematical	12 1/25: 1/8 :: 16 2/3% : 16
Worker to Tool	Physician: X-Ray:: Actuary: Statistics
Nonsemantic (Rhyme)	Hoe: Roe:: Though: Flow

Note. From "Miller's Analogy Test", by W. Bader & Burt, 1985, p.7-8.

written multiple-choice tasks where incomplete proportional analogies of the form “A is to B as C is to?” are presented and the youth must select the appropriate D item from several alternatives. An example of a verbal proportional analogy problem would be “Five is to number as black is to ?” (white, grow, color, plant, hardware). In lieu of the obscure “is to as” syntactic phrasing, analogies are sometimes phrased “is like” or “goes with”. Previous research (Sternberg & Nigro, 1980) had indicated that verbal analogies expressing functional relationships (e.g., “Shoe is to foot as hat is to head”) are easier for children to understand than those expressing other semantic relationships, such as categorical (i.e., “Lion is to animal as Christmas is to holiday”) or sequential (i.e., “Monday is to Wednesday as January is to March”).

A second type of analogy is the perceptual proportional analogy problem would consist of various visual patterns or geometric designs such as a small circle (A) and a large circle (B) paired with a small square (C) and an empty slot (D), with answer choices that include a large square and several related designs serving as foils. As with Verbal Analogical Reasoning, three pictures (A,B, and C) were shown in a matrix and a fourth (D) was left to be inferred.

A third type of analogy is the quasi-analogy (i.e., the bird uses air; a fish uses ____”). Standard verbal analogies seem to require recognition, quasi analogies do not. In summary, basically these three types of analogies have been used in educational research settings. Most of the research has focused on the verbal analogy of the proportional format.There is disagreement in the literature as to how the ability to use these different types of analogies develops.

The Development of Analogical Learning

Inductive reasoning is ubiquitous in human thinking. Children, like adults, must constantly make inferences that are not deductively valid and they all involve the transfer of the known to the unknown. Such flexible use of knowledge is often claimed as the hallmark of human intelligence. Evidence has emerged that analogies and metaphors are the language of the right cerebral hemisphere.

Neurological Considerations

There is overwhelming evidence that the use of metaphors and analogies can be a vital component in human communication. Recently, evidence has emerged of a neurological basis for the effectiveness of metaphor. According to Watzlawick (1978), metaphor and analogy are the language of the right cerebral hemisphere. It is probably an oversimiplication to say simply that the left brain processes literal, sequential, and logical aspects of language, while the right brain processes the metaphorical or analgoical aspects. Nevertheless, it does seem that there is some such division of work between the two hemispheres. Much instruction addresses the left hemisphere, this may explain why it tends to produce results slowly; presumably it influences the right brain only indirectly. On the other hand, instructional methods that address the right brain, directly- such as the use of analogies, stories and other forms of metaphor seem to produce results more quickly (Barker, 1985).

Lamb (1980) has reviewed the relationship of hemispheric specialization and storytelling and metaphors. She points out that the idea that human beings have two ways of thinking has a long history. Watzlawick (1978) describes it as such:

> There are two languages involved. The one, in which for instance this sentence itself is expressed, is objective, definitional, cerebral, logical, analytic; it is the language of reason, of science, explanation and interpretation, and therefore the language of most education. The other . . . is much more difficult to define- precisely because it is not the language of defintion. We might call it the language of imagery, of metaphor, perhaps symbols, but certainly of synthesis and totality, and not of analytical dissection. (pp. 14-15).

They also add that the latter language ('right brain language") also includes poetry and nonverbal language as expressed in facial expressions, voice tone, body postures, and movements and dance. In addition they note that "the brain's hemispheres are not specialized for different types of materials (verbal and spatial) but for different kinds of thought" (p. 82). Lamb summarizes the situation as follows:

> Recent research in neurology indicates that the two cerebral hemispheres of the human brain process information by two different strategies.The left hemispheres processes data in a sequential, one-at-a-time fashion. Logical, temporal, verbal and analytic concerns are best handled by this hemisphere. The right hemisphere processes information in a simultaneous,holistic fashion. Spatial, structural, kinesthetic, gestalt, and metaphoric considerations are best handled by the right hemisphere. The hemispheres communicate through the corpus callosum. . . (Lamb, 1980, pp. 18-19).

Experimental evidence for the different functions of the two hemispheres has come from electroenceophalographic (EEG) studies of a group of bilingual

Hopi Indian children (Barker, 1985). These children were told the same two stories in both English and Hopi, and it was found that they evidenced greater right hemispheric activity when Hopi was used than when English was used. Hopi, a Native American language, is concerned with the immediately perceivable and links speech to its context; it is much less concerned than English with time and readily allows for timelessness. Hopi is concerned with the domain of nature, not with logic and abstract ideas. The different EEG patterns observed in this study offer support for the idea of right hemispheric specialization.

Most learning involves more traditional learning strategies that involve the left hemisphere. Analogies and emotional investment access the right hemisphere of the brain. Vygotsky addresses right hemisphere involvement with language acquisition. Analogies may be successful for the learner because of this hemispheric shift . Each hemisphere is specialized for a different type of thinking or cognitive style, with the left side employing a more sequential, analytic thought process and the right a more holistic, gestalt frame of reference.

Bogen (1975, 1977) has done some extensive writing on the educational aspects of hemisphericity, indicating that Western society has overemphasized the three Rs (reading, writing, and arithmetic) in the school system and subsequently has educated students “lopsidely” toward left-hemisphere thinking rather than right-hemisphere thinking. Bogen (1975, 1977) suggested that educators should encourage more right hemisphere learning in the classroom so that the other half of the student's potential can be actualized (i.e., the artistic and musical talents, the creative insights, as well as the spatial problem-solving abilities). Bogen (1975, 1977) advocated the use of different instructional techniques to boost right-hemisphere thinking; to this end, more hands-on laboratories and field experiences should be included in the educational curriculum, at the expense of the more traditional (yet always favored) lectures and seminars.

With respect to teaching reading skills in the classroom, linguistic processing (via the "phonetic" method) also should be balanced more properly with the right-spatial type. To achieve this, a "whole word" method should consist of children visualizing an entire image of each word, in which the size, shape, and phonemic features are included. This visualization-and-say strategy not only will benefit the neglected right side, but it also will help the left in attaining a greater mastery in word pronunciation (Southgate & Roberts, 1970).

More recently, Stanish and Singletary (1987) attempted to integrate analytic and holistic instructional styles into any educational content area. They based their "ambidextrous" or balanced-brain approach on many creative games designed to develop the imagination.

The majority of information concerning children's transfer has come from a classic analogical approach or the A: B::C: ? paradigm (Brown & Clement, 1989). Children show little evidence of spontaneous transfer in the classic A B C paradigm, 20 % spontaneous transfer being the commonly reported figure for both adults and children when age-appropriate tasks are used (Brown et al. 1986; Crisafi & Brown, 1986, Gick & Holyoak, 1980). It has been claimed that below 5 years of age, transfer rarely occurs, and it is a widely held belief that the younger the learner the less likely is transfer.

The most popular view that attempts to explain this is the perceptually bound hypothesis (Carey, 1985). They are called perceptually bound, meaning that they are influenced by the appearance of things. There are three potential explanations of the seeming perceptual capture of young learners: The developmental-stage argument states that children are perceptually bound initially but then, at a later stage, consider other bases for categorization. The developmental-preference argument claims that children can use a variety of bases for partitioning their world, but they prefer to rely on perceptually salient features. The lack-of-knowledge argument states that children rely on appearance as a fall-back option when there is no other basis on which to judge. Rather than there being a developmental shift from perceptually bound to theoretically based, all conceptual systems are integrated with theory from the earliest age. In the absence of the requisite knowledge, it is difficult to imagine any other basis for partitioning other than appearance. Young children, universal novices, find themselves dependent on surface cues more often.They know little about many domains. What else can they fall back on, other than surface commonalities? (Brown & Clement, 1989). Vosniadou & Ortony (1989) would agree that it the lack of knowledge in the selected domain that is preventing the student from successfully engaging in analogical reasoning. For instance, biological knowledge evolves slowly. Initially, the child lacks the concept of living thing, differentiating plants and animals as separate categories. The young child appears to reason on the basis of naive psychology, based on intention. Older children see animals as functioning because of their membership in biological categories. These differences in basic core concepts have profound effects on the child's transfer (Carey & Smith, 1993).

As an example, Carey (1985) has shown that even 4-year-olds are capable of overcoming appearance matches to project biological properties to unknown species within the constraints set be their immature theories. Told that people have a certain organ (spleen), they project the new organ in decreasing likelihood to mammals, birds, insects, and worms, but not to inanimate objects. But when taught that a bee has the organ, they fall back on perceptual similarity (bee/bug) as the basis of transfer (Carey, I985).

Gelman and Markman (1986) also looked at biological category membership and perceptual similarity. Four-year-olds were shown two pictures, for example, one that looked like an ostrich and one of a bat with outstretched wings. They were taught a new fact about each. In this example, they were told that the ostrichlike bird gives its baby mashed up food and the bat feeds its baby milk.They were then required to infer which of the facts applied to a third picture that looked very much like one of the preceding two but was given the same category label as the picture it did not physically resemble. No child responded consistently on the basis of perceptual matches, whereas 37 % of 4-year-olds consistently relied on shared category to draw inclusions, even though perceptual similarity would lead to a different conclusion. Another theoretical position states that learners make a developmental shift from being perceptually bound to looking for relationships to determine the similarities.

Structure Mapping Theory

There is another prominent theory that explains how comprehension is facilitated by analogy use. This theory, (Gentner, 1989), known as the structure mapping theory, posits that the structure of a base or known complex knowledge system (i.e., the analogy) is mapped onto a target or unknown domain (Gentner, 1983). This theory assumes network-like representations of concepts in memory, called schemata, in which underlying structural relationships and superficial surface attributes are coded along with each concept. For example, when we read that the atom is like a miniature solar system, the implication is that the solar system and the atom have similar relationships among their component parts- smaller bodies revolving around a larger one in fixed path patterns. Surface similarity (i.e., the sun is hot and large and contains burning gases) is not implied. Good scientific analogies maintain much of their underlying structure in the transfer from base to target domains, whereas surface features are of minimal importance (Gentner, 1988). An analogy with clear parallel structural relationships is not simply a weak comparison; it can play a generative role in the formation of new schemata in which the relations among objects in the base domain are preserved in the target domain. Gentner (1989) describes the relationship between analogy and similarity in her delineation of the various types of analogies.

Similarity. Similarity and analogy are fundamental in human cognition. They are crucial for recognition and classification, and have been associated with scientific discovery and creativity. Successful learning is generally less dependent on the memorization of isolated facts and abstract rules than it is on the ability to identify relevant bodies of knowledge already stored as the starting point for new learning. Similarity and analogy play an important role in this process- a role that in recent years has received much attention from cognitive scientists. This increased interest is related to the controversial position that human reasoning does not always operate on the basis of content-free general inference rules, but rather, is often tied to particular bodies of knowledge and is greatly influenced by the context in which it occurs. In a reasoning system of this kind of and applying the same inference rules to them. Rather successful learning often depends on the ability to identify the most relevant bodies of knowledge that already exist in memory so that this knowledge can be used as the starting point for something new.

There is general agreement that analogical reasoning involves the transfer of relational information from a domain that already exists in memory, usually referred to as the source or base domain, to the domain to be explained, referred to as the target domain. Similarity is implicated in this process because a successful, useful analogy depends upon there being some sort of similarity between the source domain and the target domain and because the perception of similarity is likely to play a major role in some of the key processes associated with analogical reasoning. There are many different theoretical frameworks that attempt to describe the role of similarity, the amount of domain knowledge and analogy. The distinction of the different types of similarity is germane to the categorization of the analogy.

Kinds of Similarity. Distinguishing different kinds of similarity is essential to understanding learning by analogy and similarity. Gentner (1989) describes several types of similarities Table 3 describes the different classes of similarities according to the number of shared relationships and attributes. Besides analogy, other kinds of similarity can be characterized by whether the two situations are alike in their relational structure, in their object descriptions, or in both. In analogy, only relational predicates are mapped. In literal similarity, both relational predicates and object attributes are mapped (i.e., Milk is like water because both are liquids and smooth). In mere-appearance matches, it is chiefly object attributes (nouns and adjectives) that are mapped, as shown in Figure 1.

Table 3
Kinds of domain comparisons

Similarity	Attributes	Relations	Example
Literal Similarity	Many	Many	Milk is like water.
Analogy	Few	Many	Heat is like water
Abstraction	Few	Many	Heat flow is through-variable
Anomaly	Few	Few	Coffee is like the solar system
Mere Appearance	Many	Few	The glass tabletop gleamed like water

Note. From "The mechanisms of analogical reasoning", by S. Vosniadou & A. Ortony (Eds.), 1989, *Similarity and Analogical Reasoning*, p. 206.

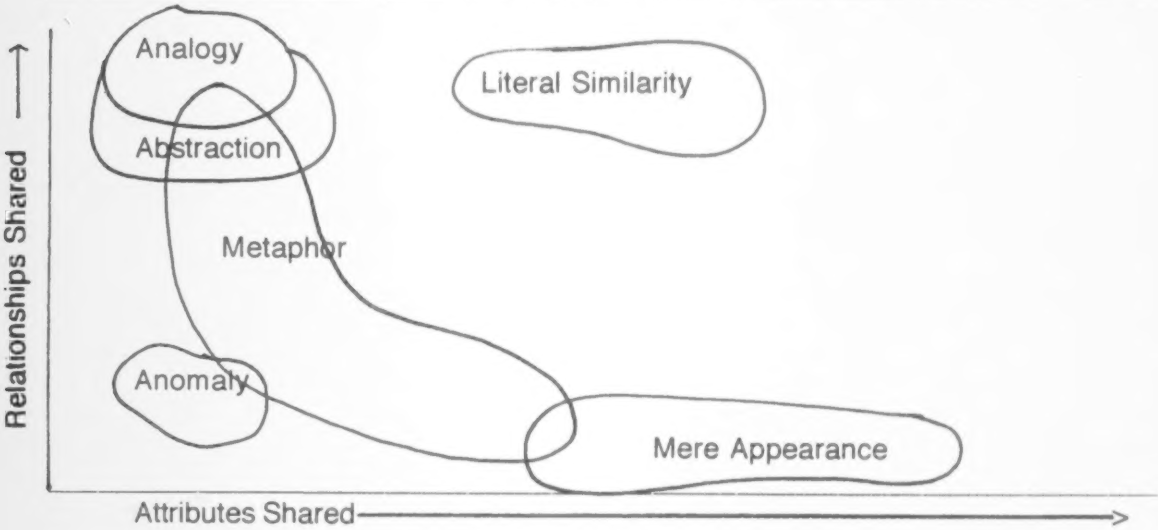

Analogy
Abstraction
Literal Similarity
Metaphor
Anomaly
Mere Appearance
Relationships Shared
Attributes Shared

Figure 1. From "The mechanisms of analogical reasoning", by S. Vosniadou & A. Ortony (Eds.), 1989, *Similarity and Analogical Reasoning*, p. 207.

Analogy is demonstrated by the water/heat example which conveys that a common relational system holds for the two domains: Pressure difference causes water flow, and temperature difference causes heat flow. Literal similarity is explained by the comparison "Milk is like water", which conveys that much of the water description can be applied to milk. In literal similarity, both object attributes, such as FLAT TOP (water) and CYLINDRICAL (beaker), and relational predicates, such as the systematic causal structure are mapped over. A mere-appearance match is one with overlap in lower-order predicates- chiefly object attributes- but not in higher-order relational structure as in "The glass tabletop gleamed like water."

Mere appearance matches are in a sense the opposite of analogies. Such matches are sharply limited in their utility. For example, little beyond physical appearance is shared between the tabletop and water. These matches; however, cannot be ignored in a theory of learning, because they often occur among novice learners (Gentner, 1989).

Gentner (1989) also describes another type of match, the relational abstraction. An example is the abstract statement, "Heat is a through-variable", which might be available to a student who knew some system dynamics. This abstraction, when applied to the heat domain, conveys much the same relational structure as is conveyed by the analogy: that heat (a through-variable) can be thought of as a flow across a potential difference in temperature (an across-variable). The difference is that the base domain contains only abstract principles of thought-variables and across-variables and variables; there are no concrete properties of objects to be left behind in the mapping.

Gentner (1989) claims that these contrasts are continuous, not dichotomies. Analogy and literal similarity lie on a continuum of degree-of-attribute-overlap. In both cases, the base and target share common relational structure. If that is all they share, then the comparison is an analogy, assuming that the domains are concrete enough to have object descriptions. To the extent that the domains also share common object descriptions, the comparison becomes one of literal similarity. Another continuum exists between analogies and relational abstractions. In both cases, a relational structure is mapped from base to target. If the base representation includes concrete objects whose individual attributes must be left behind in the mapping, the comparison is an analogy. As the object nodes of the base domain become more abstract and variable-like, the comparison becomes a relational abstraction (Gentner, 1989).

The issue of physical or surface similarity plays an important role in understanding the underlying mechanisms of analogy. Brown (1989) discusses the hypothesis that children are "perceptually bound", the hypothesis that physical appearance is of primary importance in carrying out various psychological tasks. They both also provide evidence that young children can carry out tasks based on underlying structural information, thus suggesting that children do not have a "deficit" in processing abstract structural knowledge. Brown (1989) argues that young children give the appearance of being perceptually bound because they often lack underlying abstract knowledge about a domain and so are forced to use surface or physical similarity to respond. Similarly, Dedre Gentner (1983) proposes a model of analogical development that suggests that children and novices are also perceptually bound.

Accessing the base system. What governs spontaneous access to similar or analogous situations? Gentner (1983) investigated this question, using a method designed to resemble natural long-term memory access (Gentner,1983). They first gave subjects a large set of stories to read and remember (18 key stories and 14 fillers). Subjects returned about a week later and performed two tasks: (a) a reminding task; and (b) a soundness-rating task.

In the reminding task, subjects read a new set of 18 stories, each of which matched one of the 18 original stories. Subjects were told that if any of the new stories reminded them of any of the original stories, they were to write out the original story (or stories) as completely as possible. There were three kinds of similarity matches between base and target: a) mere appearance (MA): object attributes and first-order relations match, b) true analogy (TA): first-order relations and higher-order relations match , c) false analogy (FA): only the first-order relations match. In all three cases, the base and target shared first-order relations. Other commonalities were added to create the different similarity conditions. Each subject received one-third MA, one-third TA, and one-third FA matches, counterbalanced across three groups. After the subjects had completed the reminding task, they performed the soundness-rating task. They were shown their 18 pairs of stories side by side and asked to rate each pair for soundness or inferential power of the match (with 5 being "sound" and 1 being "spurious").

The results for access were surprising. Despite subjects' retrospective agreement that only the analogical matches were sound, their natural remindings did not produce analogies. Instead, they were far more likely to retrieve superficial mere-appearance matches. Given mere-appearance matches, subjects were able to access original story 78 % of the time, whereas the true analogies were accessed only 44% of the time, and the false analogies 25% of the time. All three differences were significant, suggesting that (a) surface commonalities have the most important role in access but that (B) higher-order relational commonalities-present in the true analogies but not in the false analogies, also promote access. Table 4 delineates the difference among relational, double and attributional metaphors.

There is also confirmation for the other side of the coin: that surface commonalities do promote access (Novick, 1988; Reed & Ackinclose, 1986; Ross, 1987). For example, Ross (1987) found clear effects of surface similarity in determining which earlier algebra problems subjects would be reminded of in trying to solve later problems. Reed and Ackinclose (1986) found that perceived similarity, rather than structural relationships, was the best predictor of whether subjects solving algebra problems would apply the results of a previous problem to a current problem. Overall similarity, especially surface similarity, appears to be a major factor in accessing material in long-term

Table 4
Relational, Double and Attributional Metaphors

Type of Metaphor	Relational	Attributes
Relational Metaphors		
A cloud is like a sponge.	R1) Both hold water	A1) Both are soft
	R2) Both give off water	A2) Both are fluffy
A tire is like a shoe.	R1) Both are used to move	A1) Both made of rubber
	R2) Both cover the bottom	A2) Both can be black
Double Metaphors		
Plants stems are like drinking straws.	R1) Both can be used to	A1) Both are long
	R2) Both draw liquid up	A2) Both are thin
Grass is like hair.	R1) Both grow quickly	A1) Both are long
	R2) Both cover and protect something	A2) Both are skinny
Attributional Metaphors		
Jelly beans are like balloons.	R1) Both are fun at parties	A1) Both can be many colors
	R2) Both can be tossed in	A2) Both are round
A snake is like a hose.	R1) Both squirt liquid	A1) Both are long
	R2) Both can curl up	A2) Both are wiggley

Note. From "Metaphor as structure mapping: The relational shift", by D. Gentner, 1988, *Child Development*, 59, p. 51.

memory for both experts and novices.

Mapping the base and target systems. The central idea in structure-mapping is that an analogy is a mapping of knowledge from one domain (the base) into another (the target), which conveys that a system of relations that holds among the base objects also holds among the target objects. Mapping triggers access of a domain. Thus an analogy is a way of focusing on relational commonalities independently of the objects in which those relations are embedded. In interpreting an analogy, people seek to put the objects of the base in one-to-one correspondence with the objects in the target so as to obtain the maximum structural match. Objects are placed in correspondence by virtue of their like roles in the common relational structure; there does not need to be any resemblance between the target objects and their corresponding base objects. Central to the mapping process is the principle of systematicity: People prefer to map connected systems of relations governed by higher-order relations with inferential import, rather than isolated predicates (Gentner, 1989). Table 5 illustrates Gentner's three types of metaphors using specific examples.

The effect of the analogy is then not so much to import new knowledge as to focus attention on certain portions of the existing knowledge (both the access and mapping). A review of the research on analogical use in adolescents is not recent, most of the research was conducted before many of the new emerging theories on cognitive development were formulated. In addition, the research doesn't look at analogy as an end in itself.

Table 5
Three Types of Metaphors

Metaphor Type	Examples of the Metaphor
Relational Metaphors	The moon is like a light bulb.
	A camera is like a tape recorder.
	A ladder is like a hill.
	A cloud is like a sponge.
	A roof is like a hat.
	Tree bark is like skin.
	A tire is like a shoe.
	A window is like an eye.
Attributional Metaphors	Jelly beans are like balloons.
	A cloud is like a marshmallow.
	A football is like an egg.
	The sun is like an orange.
	A snake is like a hose.
	Soapsuds are like whipped cream.
	Pancakes are like nickels.
	A tiger is like a zebra.
Double Metaphors	A doctor is like a repairman.
	A kite is like a bird.
	A hummingbird is like a helicopter.
	Plant stems are like drinking straws.
	A lake is like a mirror.
	Grass is like hair.
	Stars are like diamonds.

Note. From "Metaphor as structure mapping: The relational shift" by D. Gentner, 1988, *Child Development*, 59, p. 52.

Analogy Research in Adolescents

Analogy As An End

Achenbach (1969) found that children in the intermediate and early secondary school grades differ widely in the extent to which they use word association as a means of choosing one from among several response options. Moreover, correlations between performance on IQ tests and school achievement were substantially lower for children who relied heavily on free association to solve analogies than for children who apparently relied primarily on reasoning processes. In addition, this study was conducted some time ago before we had any understanding about knowledge and context.

Luntzer (1965) presented children of ages 9-17 with verbal analogies varying in formal complexity. The simplest analogies had just one term missing, whereas more complex analogies had two analogy terms missing. As predicted, analogies with one term missing were simpler than analogies with two terms missing. To Luntzer's surprise; however, children had great difficulty with even the simplest analogies until about 9 years of age and did not show highly successful performance until the age of eleven. Luntzer concluded that even the simplest analogies required higher-order reasoning of the kind associated with formal-operational performance. According to Smith & diSessa (1993), analogical use it context dependent. These studies were again, conducted thirty years ago before we had any understanding of the relationship between knowledge and context. The more recent research doesn't look at analogical reasoning in this way.

Analogy An A Means To An End. Treagust & Harrison (1993) demonstrated that a competent teacher can integrate the systematic approach of analogical teaching into a teaching repertoire resulting in student conceptual understanding of the phenomena as expected at the ninth grade level. In this study, the teacher was trained to teach with analogies, using the TWA (Teaching With Analogy) model. This model included introducing the target concept, cueing the students' memory of the analogous situation, identifying the relevant features of the analog, mapping the similarites between the analog and the target concepts, and drawing conclusions about the target concepts. The analogies used to differentiate the wave nature of light from water wave characteristics were: the conduction of heat through a solid was likened to the domino effect, the slowing of light and its refraction as it passes from air into glass was demonstrated using a pair of wheels rolling from a hard surface, and the mole concept was taught using three short anaolies in which the particles of a mole were likened to dollars, oranges, and rice grains. They said, for analogies to be effective, it appears that the analogy be familiar to as many students as possible, that shared attributes be precisely identified by the teacher and/or students, and that the unshared attributes should be explicitly identified. This suggests that there may be more power in student-generated analogies than in teacher-generated analogies, if the base domain is to be familiar to the students.

A significant body of research suggests that although analogies are commonplace in human communication, they are not as effective in the classroom as might be expected (Duit, 1991). Use of analogies may generate misconceptions and this is especially so when the learners are unfamiliar with the analogy (Gentner, 1989).

The question raised by these and other studies is whether students can economically and repeatedly employ analogical reasoning skills in the same way as an experienced scientist: Emulating the analogical reasoning of scientists and philosophers may be too much to expect of unsophisticated thinkers. However, research findings state that the effectiveness of analogical instruction can be improved by training students in analogical reasoning (Friedel, Gabel, & Samuel, 1990; Gentner, 1983). These studies; however, did not consider the role of domain knowledge in the development of analogical thinking nor did they consider spontaneous use of analogies.

Zook and Maier (1994) demonstrated that eighth grade biology students' ability to process an analogy and respond to factual information was related to verbal ability, gender and was context-specific. Fewer incorrect inferences were generated by female students who had high verbal aptitude scores and who processed the analogy with a specific context. They also found that when students were provided with a clear instructional purpose, it helped them establish processing goals; however, they did not consider the mapping decisions of the expert and the novice learner.

The results of this study provide preliminary evidence that the mapping processes of analogies is influenced by learner domain knowledge structure, processing goals, analogical reasoning ability and mapping support. These instructional and learner variables undoubtedly interact differently across individual learners and specific analogies. An area that needs to be examined is the effect of the amount of domain-specific knowledge in science on the mapping decisions of novice and expert learners and whether or not their mapping ability is context dependent.

Analogy Use Sensitive to Content Knowledge

Alexander and Kulikowich (1991) examined the role domain knowledge, analogic reasoning ability, and interactive knowledge played in the comprehension of scientific exposition. Three experiments involved sixth graders, high-school students, and college undergraduates. Data included scores on expository passages on topics in human biology/immunology, the Advanced Progressive Matrices analogic reasoning test and and interactive knowledge test composed of human biology/human immunology terms. Results showed that the variables predicting performance on the nonanalogic and analogic tests and the variables discriminating between above average and below-average students differed across the grade levels with less integration of content knowledge and analogic reasoning ability occurring for college students. They also said that students need some degree of biology knowledge before analogies were effective. A limitation of this study was that they used a test of general cognitive ability, the Advanced Progressive Matrices as a measure of analogical reasoning ability which assumes that a general measure of analogical reasoning is similar to analogical reasoning with the biology domain.

In summary, there is some evidence of success with teacher-generated verbal analogies at ages ten through eighteen; however, these studies did not address the issues of expertise/novice use of analogies nor did they consider the effect of a familiar domain. Children as young as four-years old can reason analogically under certain circumstances. Also, much of the research is conducted from a "teacher-generated" point of view, for instance, when the students are given analogy problems to solve. There are few studies of students spontaneously using analogies or "students generating" analogies. It seems as though the organization of knowledge in a familiar or base domain would have an impact on the ability to successfully use analogies.

Relationship to Intelligence. Research has indicated that analogical reasoning is an important cognitive construct that steadily improves throughout the elementary, middle, and high school years and is predictive of intellectual capacity and academic achievement (Kaufman & Kaufman, l983; Sternberg , 1985).

Analogy has also played a key role in Piaget's (1926) theory of intelligence. Luntzer (1985) has argued that formal reasoning in the Piagetian sense can be identified with recognition of the higher-order relation that links the relation between A and B to the relation between C and D. Piaget, has suggested three levels in the development of analogical reasoning. In the first level, characterizing the performance of children of ages 5-6, children can arrange objects such as pictures into pairs; but the children ignore higher-order relations between pairs of pairs. Thus, although these children can link A to B and C to D, they cannot link A-B to C-D. In the second level, characterizing the performance of children from about 8-11 years of age, children can form analogies; but when they are challenged with counter suggestions, these children readily rescind their proposed analogies. Piaget takes this as evidence of only a weak or tentative level of higher order reasoning ability. In the third level, characterizing the performance of children of ages 11 and above, children form analogies are able explicitly to state the conceptual bases to the experimenter.

Sternberg (1977) is of the opinion that there is empirical support for the claim that the ability to reason analogically is closely related to general intelligence. But other studies point out that it depends very much on what is meant by analogical reasoning and general intelligence whether such a point of view is adequate. Enyeart (1979), for instance, found no general correlation between analogy use and Piagetian levels. There was only a significant correlation between the use of formal analogies (i.e., analogies representing proportions) and formal operational thought.

In summary, when students are tested for analogical ability with the goal using analogies for the sake of using analogy, ability tends to be increase with age; however, these studies did not consider using analogies within a specific context or using analogies as a means to an end. Vosniadou & Ortony (1989) & Gentner (1989) state that children as young as four-years old can reason analogically given a proper context.

There are also studies that investigated the use of analogies for students at different levels of ability. Gabel and Sherwood (1980) reported a tendency for their analogies to be more effective for students of lower formal reasoning ability and not especially useful for more capable students. It seems that the target has to be sufficiently difficult and challenging for the learner Sutala and Krajcik's (1988) study points in a similar direction. They found that students with high cognitive abilities benefited more from creating their own analogical connections, whereas students with low abilities benefited more from having the teacher help make the analogical connection.

Children with learning disabilities may have a problem in interpreting metaphor and need specific guidance and practice (Baechle & Lian, 1990). Their study found that direct feedback and practice could significantly increase metaphor performance of these children. Further descriptive analyses indicated that grade and reading levels of the subjects correlated with their metaphor performance. Alexander & Kulikowich (1991) found that gifted students consistently outperformed their nongifted peers on all cognitive analogy tasks.

It has been demonstrated that students who do well in solving verbal analogies also tend to do well with perceptual analogies (Kaufman & Kaufman, 1983). There is evidence to suggest that growth in solving analogy problems is characterized by increased speed and accuracy, greater use of systematic strategies, and improvements in the ability to solve analogies involving greater semantic or visual complexity (Kaufman & Kaufman ,1983; Woodcock Johnson, I977). Again, what develops is not the ability to engage in analogical reasoning, but the content and organization of the knowledge base on which analogical thinking is applied (Vosniadou & Ortony, 1989). If the scientists, who are considered experts in their field use analogies successfully, then an understanding of the way scientists organize their knowledge may be useful.

Scientists' Use of Analogies

"DNA is like a spiral staircase"

Gruber and Barrett (1974) analyzed Darwin's thinking during the period 1831 to 1838, when he underwent a conceptual change from holding a creationist theory of the world to that of an evolutionist. According to the record (Greene, 1959; Gruber & Barnett, 1974), Darwin's search for a theory to explain the evolution of organisms involved a number of initially unsuccessful trials and a good deal of groping until a key event occurred. Darwin saw in Malthus' writing a key idea that he could borrow an use to explain evolution. That key idea was that artificial selection of domesticated plants and animals was analogous to what presumably occurs in nature and could account for a change in evolution of species.

The example of Darwin's use of the analogous process of artificial selection suggests that analogy plays a central role in theoretical concept development. The pattern that allowed Darwin to make sense of his data was analogous to the pattern in the process of artificial selection. Most researchers have referred to the process as analogical reasoning (Karplus, 1979; Lawson , 1994) or analogical transfer (Holland, Holoyoak, Nisbett & Thagard, 1986).

Examples of abduction are numerous in the history of science. Kepler borrowed the idea of the ellipse from Appolonius to describe planetary orbits. Mendel borrowed patterns of algebra to explain heredity. Kekule borrowed the idea of snakes eating their tails (in a dream) to determine the molecular structure of benzene, and Coulomb borrowed Newton's ideas of gravitational attraction to describe the electrical forces that exist at the level of atomic particles (Lawson, 1994).

Many other scientists have said that they obtained their insight or illumination with the guided use of an analogy. A few important analogies used by biologists are: Hermann von Helmholz who developed his theory of hearing on the analogy of musical instruments, such as the harp or the piano, his theory was that the fibers of the basilar membrane resonate to external frequencies somewhat like wires in a harp or piano. Watson & Crick describe DNA and RNA codes similar to an alphabet spelled with four letters. The structure of DNA is sometimes likened to a spiral staircase (Dreistadt, 1968).

Norbert Weiner, Gray Walter and W.S. McCulloch also used the analogy of television to explain brain processes. The alpha wave, which is the normal rhythm of the visual cortex, is supposed to serve as a scanning and carrier wave which picks up "the picture" coming into the brain and codes it somewhat as TV signals are coded, and then the signals are carried to different parts of the cortex for decoding. Any of the cortical areas can act as TV receivers by decoding the signals carried on alpha waves. This theory is supposed to solve the problems of equipotentiality and recovery of brain functions. Abduction, the use of analogy to apply old ideas in new situations to invent new concepts and new explanations, seems to be all-pervasive (Lawson, 1994).

Analogies could be a tool to reorganize existing knowledge in a new or more generative fashion that also bring together previously unrelated concepts. According to some constructivists (Brooks, 1993), effective learning takes place when the learner makes meaning out of the acquired knowledge. In order for new domain-specific information to be understood and remembered, it must be meaningful to the learner (Bruner, 1986). Meaningfulness depends on the learner's success in finding or creating connections between new information and preexisting knowledge. One way by which these connections are made are through the use of analogies. Analogy use forces one to reexamine new knowledge to meet the demands of their prior knowledge. Analogies are a technique to link the old knowledge to the new knowledge. There are three major types of analogies that have been used in the educational setting.

Analogy Use In Science Education

" Electricity is like the flow of water"

" Moving gas molecules are like bouncing billiard balls"

Research findings show that analogical reasoning is an important cognitive process that steadily improves throughout the elementary, middle, and high school years and is predictive of intellectual capacity and academic achievement (Achenbach, 1969, Kaufman & Kaufman, 1983, Sternberg, 1985).

Metaphors are enormously valuable in science (Howard, I989). Much has been written about how scientists often resort to a metaphor to try to make some sense of an area. An often-quoted example is the view of the heart until about the sixteenth century. It was understood as like a furnace, which warmed blood. The function of breathing was to stop it from overheating! But then the water pump was invented and the furnace metaphor was abandoned for the pump one. The kinetic model of gases is based on an analogy to bouncing billiard balls.

Analogical reasoning occurs when an individual draws upon familiar experiences to understand new experiences more fully (Sternberg, I985). This process often arises in educational settings when analogies are used to assist in the explanation of complex concepts (Simon, I985). For example, at the preschool level, a teacher might explain the growth of a child's body by likening it to the stretching of Silly Putty, whereas at the high school level, the movement of molecules inside a hot air balloon might be likened to people dancing in a crowded ballroom. It has been demonstrated that youngsters who do well in solving verbal analogies also tend to do well with perceptual analogies (Lorge, Thorndike & Hagen, 1966), a finding that is consistent with the similarities of both tasks. There is evidence to suggest that growth in solving analogy problems is characterized by increased speed and accuracy, greater use of systematic strategies, and improvements in the ability to solve analogies involving greater semantic or visual complexity (Kaufman & Kaufman, 1983, Lorge & Thorndike, I966, Woodcock & Johnson, 1977, Sternberg, 1985).

Teachers' Analogical Explanations

Recent interest in the use of analogies in science education has been centered around several aspects of analogy including teachers' analogical explanations in the classroom. Despite almost a decade of research generated from this interest in analogies in science education, few studies have investigated or described the effectiveness of analogies in the classroom. Thiele & Treagust (1994) describe an interpretive examination of four teachers' use of analogies to teach chemistry. They examined how teachers use analogies when they are teaching specific areas of the chemistry subject matter. They found that teachers used analogies when they considered that the students had not understood an initial explanation (i.e., in response to blank faces or slightly puzzled gazes). The students who provided the stimulation for an analogical explanation were often from the less academically able subgroup. This observation suggests that analogical explanation may be offered more frequently to less academically able students, supporting the findings of Friedel et al. (1990) that analogies may be more effective for students of lower formal reasoning ability, but not especially useful for the more capable students.

They also found that teachers rarely preplan their analogies; the analogies were direct responses to subtle student stimuli. In terms of the selection of the analogy, teachers tended to draw upon their own experiences or their own professional reading as a base or source of analogs. For example, one teacher described a mountain system in Switzerland rather than the hill regions near to the school when he used the mountain pass analogy for activation energy and catalysis. Table 6 describes some analogical explanations from a chemistry class. In addition, Thiele & Treagust (1994) found that pictorial analogies were frequently used in the lessons.

Another interesting result was the fact that teachers varied the extent of mapping depending upon various circumstances. Depending on the "level of enrichment" analogies were classified as simple where "target" is like "analog" with no further explanation, enriched indicated some statement of the shared attributes or limitations, and extended involved several analogs or several attributes of one analog used to describe the target. Analysis of the analogies employed revealed that the teachers had used simple analogies (36%), enriched analogies (42%), and extended analogies (22%) with little clear

Table 6
Chemistry Teachers' Analogies

Analog (Base)	Target
Energy Effects	
Pole vaulter attempting a vault	Activation energy
Car precariously located at the top of a hill.	High energy of the activated complex.
Reaction Rates	
Students hurdling hurdles of different heights	Rates of reactions having different activation energy.
The student ball/dance	Increase in molecular velocities causing an increase in the number of collisions.
Pushing a car around a side road	Ease of catalyzed reaction mechanism.
Chipmunks storing food before winter	Exothermic and endothermic reactions.
Chemical Equilibrium	
Breaking apart a pen and its cap	Energy to break chemical bonds.
Water flowing in and out of a sink	Constant dynamic properties in a steady state open system.
People moving in and out of a shop	Rates of forward and reverse reactions for equilibrium.

Note. From "An interpretive examination of high school chemistry teachers' analogical explanations", by R.B. Thiele & D. F. Tragust, 1994, *Journal of Research in Science Teaching*, Vol. 31, No. 3, p. 231.

preference for any one type.

In summary, in considering how these teachers' used their own analogies, Thiele & Treagust (1994) argue that there are two key competencies possessed by these teachers that resulted in the provision of useful analogical explanations. The first of these competencies lies in the teachers' excellent content knowledge; the second being their experience with how students learn and the need for alternative representations for some students. In addition, each of these teachers had good relationships with their students, and the students appeared to be attentive to the instruction and actively involved in the class. Teachers generally drew on analogs that were more familiar to the teacher than the student experiences, and this appeared to result in difficulties for some students. A limitation of the study is that they did not consider having the students generate their own analogies. In assessing the student analogies, it would be easier to find the break down in the students conceptual thinking.

Teaching Models Using Analogies

There are four major models that are used in the research as an instructional method in teaching scientific concepts through the use of analogies. They all have the common element of mapping a base to a target domain. Gentner's model characterizes the subprocesses of analogical use more so than the other models.

The Structure Mapping Theory

This theory starts from the idea that "a relational structure that normally applies in one domain can be applied in another domain" (Gentner, I983). It is based on theories of propositional networks. Gentner (1989) distinguished four kinds of similarities: 1) . Analogy. Only (or at least mainly) relational predicates are mapped and no (or very few) object attributes, 2). Literal similarity. Both relational predicates and object attributes are mapped, 3). Relational abstraction. Abstract relational structures of a base domain are mapped. There are no concrete properties of objects to be left behind in the mapping and 4). Mere-appearance match. Chiefly object descriptions are mapped. There are no strict distinctions between the kinds of similarities. Viewed within the framework, there are no principal differences between analogies and relational abstractions. The latter are viewed as analogies of a higher level. Relational abstractions are said to possess the most inferential power in the learning process. Literal similarities are viewed as much less valuable in this respect, and more-appearance matches as of almost no value. But access is much more likely with literal similarities and relational abstractions. An important principle of the structure-mapping theory is the systematicity principle: "a predicate that belongs to a mappable system of mutually interconnecting relationships is more likely to be imparted into the target than an isolated predicate " (Gentner, 1983, p. 207).

The General Model of Analogy Teaching (GMAT)

Zeitoun (1984) has developed a model for analogy use. The model comprises 9 stages with the first one being optional. In fact, there is not enough research available so far to really take this aspect into consideration. Stage 2 is essential in the planning of learning processes seen from a constructivistic point of view; what the learner already knows about and what has to be learned (the topic) is of pivotal importance. Stage 3 analyzes whether the teaching materials available already contain analogies or whether new ones must be designed. Main aspects in the following stage are familiarity and complexity of the analogies. The latter give priority to analogies providing many analogous attributes. The following stages appear to be valid for pianning and learning in general. Stage 4 is to judge the appropriateness of the appropriateness of the analogy, stage 5 to determine the characteristics of analogy, stage 6 to select the strategy of teaching and medium of presentation stage 7 to present the analogy, stage 8 to evaluate the outcomes, stage 9 to revise the stages.

The TWA (Teaching with Analogy) Model

Coming from a research perspective of text comprehension , Glynn (1989) has investigated the value of analogies used by textbook authors and they take a constructivistic position. They assert that an analogy "serves an explanatory function when it puts new concepts and principles into familiar terms. It serves a creative function when it stimulates the solution of existing problems, the identification of new problems and the generation of hypotheses". Another important idea concerns the value of looking for the superordinate concept, which can be applied to both the analog and the target. Water circuits and electric circuits, for instance, both are circuits. Glynn et al. (1989) see some "creative" function in such searches for the superordinate: "The identification and naming of the superordinate concept can suggest analogies, it also can stimulate students to generalize what they have learned and apply their learning to other concepts" (p. 323).

The TWA model has been developed on the basis of theoretical considerations concerning analogy use, empirical studies on analogical reasoning and an analytical study about analogy use in physics textbooks. The TWA model contains the following six operations: 1). Introduce the target concept 2). Recall analog concept 3). Identify similar features of concepts 4). Map similar features 5). Draw conclusions about concepts 6). Indicate where analogy breaks down. Treagust & Harrison (1993) utilized the TWA model with a Grade 10 optics class on refraction of light. The analogy likened a ray of light as it passes from air into glass to a pan of wheels that changed direction as the tolled obliquely from a hard surface onto a soft surface. The study indicated that a competent teacher can integrate this systematic approach into a teaching repertoire resulting in student conceptual understanding of the phenomena as expected at this level of science education. For analogies to be effective, it appears essential that the analogy be familiar to as many students as possible, that shared attributes be precisely identified by the teacher and/or students, and that the unshared attributes should be explicitly identified.

The "Bridging Analogies" Approach

Clement and a group of colleagues have developed a promising approach to "remedying" students misconceptions via what they call "Bridging analogies" (Brown & Clement, I989). Their work starts from research findings in the area of students' conceptions. There is, for instance, an abundance of empirical evidence that analogy use often fails because (1) students do not understand the analog properly; and (2) students are not able to draw the analogies intended.

The main idea of the "bridging analogies" approach is based on the two deficiencies mentioned. Clement (1989) and his colleagues therefore very carefully searched for analog situations that trigger a correct intuition, i.e., as in intuition that can be developed toward understanding the target situation (a similar starting point is taken by Stavy, I988). They call these analogs "anchors" (or anchoring examples). But even analogy teaching starts from analogs familiar to students, it often fails because the "jump" (so to speak) from the analog to the target is too big. The big jump is, therefore, split into smaller ones that can be mastered.

The bridging analogy approach could be illustrated through the explanation of " a book is lying on a table". It is well known from students' conceptions research than most students have severe difficulties in comprehending that the table "pushed up" the book, i.e., that the table is acting on the book via a force. According to these students, forces are attached mainly to active things. The table is not active, hence, there is no force on the book caused by the table. To guide the students toward understanding the target situation, namely, that there is an upward force acting on the book due to the action of the table. A spring is compressed by a finger. In this case, there is obviously (according to Brown & Clement, 1989) a force acting on the finger caused by the spring. This situation, therefore, triggers the correct intuition. From this anchoring situation, they proceed toward the target situation via two bridging situations, namely, a book lying on foam and a book lying on a thin board.

Summary of Analogical Instructional Methods

The "bridging analogies" approach seems promising. The approach is deliberately based on a constructivistic framework. The teaching strategy used is therefore very student-oriented, involves main aspects of negotiation of views, and employs aspects of Socratic dialogue. A main problem with the approach is that there may not be enough good anchoring situations and bridging analogies available. Students' conceptions and students' ideas in many fields are different from scientific views. It cannot, therefore, be taken for granted that anchoring situations can be found. Quite often it appears that these situations have to be "created" by developing students' alternative ideas in the analog domain via conceptual change learning. Not all students (especially younger ones) will intuitively trigger the correct idea that the spring is acting back on the finger because the finger is the active partner in their view, not the spring.

The TWA model undoubtedly is of great help when using analogies in teaching but it only provides a general structure, a proposal of steps to be followed. How these steps are taken is the essential issue- and Glynn et al. (1989) are aware of this. It has to be done in the developed "spirit" if analogies are to be of real use. They neglected to address that there is a need to consider the students' background so that the chosen analogy is familiar to as many students as possible. Also, the shared attributes should be precisely identified by the teacher and/or the students, and third, where the analogy breaks down should be explicitly identified. At the same time, multiple analogies do not necessarily lead to safety in numbers because a poorly chosen second analogy could undo the benefit of the first and vice versa.

Summary

The most frequently noted instructional problem is that of inert or ritual knowledge (Alexander, 1992). Instead of using their new knowledge, which seems to have been mastered according to classroom tests, students often revert to their inappropriate preinstructional conceptual frameworks (misconceptions) in real-life, problem-solving situations (Tobin et al., 1988). To avoid these problems, constructivists recommend that teachers present knowledge as a whole in a natural context, without the use of textbooks or teacher-directed instruction (Gunstone, White & Fensham, 1986). Support for this approach grows out of the belief that direct instruction prevents meaningful understanding.

The research on expertise indicates that experts organize knowledge differently and their expertise seems to be domain specific. However, Smith, diSessa & Rochelle (1991) suggests that novices intuitively reason like experts if they are in a familiar domain, that we are all experts in some domain. This suggests that expertise can be defined according to the organization of knowledge in a familiar domain. Unfortunately, traditional teaching practices in science do not reflect our best understanding of how students learn. Historically, analogies have been used by the scientific experts (Treagust & Harrison 1993). What works for the investigative scientist may be of value to other learners.

Most research on analogical reasoning has been used with the goal of using analogies for analogy sake and/or using analogies as a means to an end with teacher-generated tasks. These dated studies reported that the ability to reason analogically under these circumstances seems to increase developmentally as a result of age, not the amount of knowledge. Some researchers argue that not all students are able to reason analogically, but Vosniadou & Ortony (1989) argue that what develops is not the ability to engage in analogical reasoning per se but the content and organization of the knowledge base on which analogical reasoning is applied. The richer and more tightly structured one's representation of a system is, the easier it becomes to see the structural similarities between it and other systems and the greater the possibility of identifying productive analogs. It seems that the similarity that one perceives is dependent on the amount of domain knowledge.

There is controversy concerning to which academic ability group analogies are most useful. Some suggest that low ability students have difficulty understanding the literal meaning much less the figurative; others suggest that low ability students benefit more from analogies and experts don't need them. However, this research has been conducted from a teacher's perspective with teacher-generated analogies. Wong (1993) reported that student-generated analogies for undergraduates were more beneficial for the expert students and novices or low ability students benefitted more from the teacher-generated analogies. Wong didn't attempt to explain the reasons for the differences in performance.

Using a constructivist stance that assumes beginning with the student's prior knowledge, student-generated analogies seem a more appropriate instructional technique than teacher-generated analogies. It seems that student-generated analogies would be more interesting, provide less of a threatening situation, provide a better way of communicating, access right-hemisphere activity and could provide a flexible and effective alternative to traditional methods of instruction.

The research questions were:

1. Are teacher and student-generated analogies more effective than traditional instruction in bringing about change in students' understanding of a given scientific concept?

2. What is the nature of the change?

   a. How are student-generated and teacher-generated analogies related to the student's subject-matter knowledge?

   b. How do the subprocesses of analogical reasoning in expert and novice science students compare?

Chapter 3

METHOD

Participants

The participants in this study were 269 eighth grade students (mean age=13.1-14.5 years old) enrolled in a public school district in a northern suburb of Chicago, Illinois. The researcher used her class of 135 students and another cooperating teacher's class of 134. The researcher's class had been using analogies all year, and, according to teacher documentation, the students in the second class had not been using analogies. Because of the language demands of this task, only students whose primary language was English participated in the study. The study included twenty-six boys with auditory and visual memory disabilities and seven girls with weaknesses in visual organization and conceptualization. These thirty-three individuals had a diagnosis of learning disability. All students and parents signed an informed consent indicating that the scores would be confidential and used solely for the purpose of this research study (Appendix A).

Procedure

The participants were divided into a total of six groups. Three groups were organized within the cooperating teacher's class and three groups within the researcher's class. These three groups consisted of a) control group from both the researcher's class (n=44) and the cooperating teacher's class (n=44) that received traditional instruction (total n=88), b) a group of students from both the researcher's class (n=44) and the cooperating teacher's class (n=44) that generated their own analogies as an instructional method and, c) a group from both the researcher's class (n=41) and the cooperating teacher's class (n=41) that received a teacher-generated analogy for instruction (n=82). The experimental design is shown in Table 7. All research was conducted during the spring. The material and tests used for this research was integrated into the regular curriculum for the students.

Table 7
Experimental Design

	Student Distribution	
Instructional Method	Class 1 (researcher's class)	Class 2 (cooperating teacher's class)
Control Group	44 students	44 students
Student-generated Group	44 students	44 students
Teacher-generated Group	41 students	41 students

Protein synthesis was chosen because it is a difficult topic for middle school students to master. Molecules cannot be seen, even under powerful microscopes, so students have to take their existence on faith and build knowledge structures of molecules and molecular behavior without having direct, concrete experience with molecules. The information was chosen from a series of middle school science textbooks, titled Heredity, (Maton, Hopkins, Johnson, LaHart, McLauglin, Warner & Wright,1994).

Pretest. To assess prior knowledge of protein synthesis, Heredity (Maton et al., 1994), was used to construct three forms of the twenty-question multiple-choice test. To minimize the effects of learning from the test, three different forms of the test were constructed. One week before the delivery of the instruction, all of the students completed a twenty-question, multiple-choice pretest, Form A (Appendix B), and an open-ended two question short answer pretest (Appendix C) that assessed the defining characteristics and importance of protein synthesis.

The multiple-choice test consisted of twenty questions randomly selected from a test bank from the textbook, Heredity , (Maton et al., 1994).Content and construct validity were high because most of the worksheets that were used for instruction were from the resource materials provided to accompany the textbook, Heredity, (Maton et. al., 1994) from which the test questions were derived.The possible scores on this test ranged from 1-20, and the number of correct responses were recorded. If the student answered all of the questions correctly, he/she would receive a score of 20.

Instruction. All of the groups received four days of traditional instruction on the topic of protein synthesis. The instruction was delivered on a Thursday and Friday with homework given to be completed over the weekend. The following Monday, the students reviewed the material in different formats, depending on the group that they were in, and on Tuesday, they were posttested. The researcher taught the cooperating teacher's class first and taught her own class three weeks later.

The first day (Thursday) consisted of a review of cell organelles. This was accomplished by the researcher constructing with the students, a large cell on the whiteboard. The ten sequential steps of protein synthesis were then superimposed on the drawing as the process was explained. At the same time, the students created their own drawing on a piece of drawing paper at their desks. In addition to creating the drawings, all students received a two page handout that contained an outline of basic cellular physiology and the sequencing steps of protein synthesis (see Appendix D).

On the second day (Friday), all six groups completed an activity titled, "Protein Synthesis" from a textbook, Biology (Miller & Levine, 1991) (Appendix E). This activity required the students to review and sequence the steps of protein synthesis. The students spent thirty minutes working on this activity in groups of 2-3 at laboratory tables. The instructor reviewed the answers with the students at the end of class and asked for questions and/or clarification. At the end of class, all six groups were given a worksheet titled "Protein Synthesis: Translation" from the Biology Coloring Book (Griffin, 1986) (Appendix F). The homework assignment involved assigning colors to an illustration of the different steps of protein synthesis, and then coloring the drawing. All of the groups were required to complete this worksheet for homework over the weekend. Upon returning to school from the weekend, the student's homework was checked for completion. Ninety-nine percent of the students had finished coloring the worksheet.

On the third day of instruction (Monday), the students received different instruction depending on the group of which they were assigned. The two control groups engaged in additional practice. The control groups completed an activity titled "Cracking the Code" from Molecular Biology Concepts (Goldberg & Moulton, 1992) (see Appendix G). This activity required students to "decipher" messages written in triplet code. The students worked in groups of three to four to decipher the code.

The students in the student-generated analogy groups were given directions to create their own analogy (see Appendix H for a description). The researcher first reviewed analogies through the standard A:B::C:D format. This type of analogy involves finding the relationship between four items. The students were instructed on how to proceed to find an answer for D. The first step in solving this analogy problem is to find a relationship between two of the three given terms. There are two techniques that may be employed to determine the nature of the relationship- one using sentences and one using categories. With the sentence technique, one begins by making up a short, simple sentence using the two terms one is considering. Then one substitutes the other given term, together with each of the answer choices, in the sentence created. One should find one combination that exactly parallels the relationship expressed by the original word pair.

The second technique that could be used to solve these problems is the Category Technique that involves devising a list of common relationships between words. Examples of common categories for analogies include: synonyms, antonyms, part to whole, cause and effect, degree, etc. Once a relationship between words A and B was determined, then D could be answered.

They were then given the remaining forty-minutes to create their analogies.They were instructed to map an entire "system". A "system" meant that all of the parts of their analogy had to relate to a singular topic. For example, if the student selected the topic of automobiles, all of the components of their analogy had to relate to the automobile. One of the requirements was that they were to select only one topic from which to create their analogy. In addition to providing an illustration of their analogy, the students were asked to describe the relationships of their analogy to protein synthesis. In addition they were asked to explain the similarities and differences of their analogy to protein synthesis (see Appendix I). In some instances, the students were allowed to take their analogies home to complete them.

The last group, the teacher-generated group consisted of forty-one students from the researcher's class and forty-one students from the cooperating teacher's class. The students in this group received the teacher's explanation of the publisher's analogy of protein synthesis. This analogy consisted of a principal asking his secretary to deliver a message to one of his science teachers. The principal wanted the science teacher to construct a letter for parents about an upcoming event (this analogy is described in Appendix J).

Posttest. All students were posttested on this material twice. The students took the tests immediately after the instruction on the following day, and one month after instruction. The day following instruction (Tuesday), all students took a different form of the twenty-question multiple-choice test than the prettest ,Form B, (see Appendix K) and the same open-ended two question test as was in the pretest (see Appendix C). One month after instruction, the students took another multiple-choice test , Form C, (Appendix L) and the same open-ended two-question test (Appendix C). The analogies that the students created were analyzed and categorized according to the domain accessed and the relationships mapped. The forms of the multiple-choice test used in the post-test had similar reliability and validity as used in the pretest.

The open-ended test that consisted of two questions was given as a pretest and twice after instruction, once immediately following instruction and one-month after the instruction. The advantage of this type of test is that it allowed the students to diverge, reflect and respond in a more unique way than through the structured format of the multiple-choice test. The first question was composed of two parts: "What is a protein?" and "Why are proteins important in our lives?" The second question was: "How are proteins made in the body?" This test was given because the multiple-choice test may not have detected the knowledge and understanding of proteins that the students may have. The student's degree of understanding was recorded on a continuum of understanding and misconception.

The open-ended test was scored numerically according to Simpson (1986) as follows: 0= no response (i.e., " I don't know", "I don't understand") 1= no understanding of the concept (i.e., Repeats the question or an irrelevant or unclear response), 2= some partial understanding of the concept but the student also includes statements that indicate an overall misunderstanding , 3= a partial understanding of the concept in that students demonstrate an understanding of some components of protein synthesis, but not all of them and 4= a complete understanding of protein synthesis.

The students' analogies were categorized according to the type of similarity that they created and the words or descriptors that the student used to create their analogy (Gentner, 1990), and the topic selected for the analogy (Vosniadou, 1989). The type of similarity between the student's conceptualization and protein synthesis produced was classified according to Gentner (1990) as: an anomaly, mere appearance, literal similarity or an analogy. These types of similarities were based on the number of attributes (nouns, adjectives) and the number of relationships (transitive verbs, comparative adjectives and prepositions) used to characterize the analogy. A mere appearance contained descriptive relationships, a literal similarity contained some descriptive and some action words, and an analogy contained action relationships.

A student's analogy was considered an anomaly if it contained few attributes or relationships (i.e., Coffee is like the solar system). A mere appearance contained mainly descriptors such as adjectives to describe the relationship between protein synthesis and the student's analogy (i.e., The glass tabletop gleamed like water.) A literal similarity contained approximately an equal number of descriptive adjectives and active relationships (verbs) to describe the relationship between protein synthesis and the student's analogy (i.e., Milk is like water). An analogy contained a majority of active relationships to describe the relationship between protein synthesis and the student's analogy (i.e., Heat is like water).

The student analogies were also characterized by the topic chosen to create the analogy. The student's selected base domain was classified as near or far domain (Vosniadou, 1989). A near domain was a topic that was considered a topic of science. A far domain was a topic outside of science (i.e., shopping, clothes, war).

One month after receiving protein synthesis instruction, all of the students in the student-generated analogy group and the teacher-generated analogy group completed a questionnaire. The questions were designed to address the absence or presence of a visual imagery associated with the analogies, preference for analogy use and effectiveness of analogies. Some of the questions were: "Does protein synthesis remind you of anything familar to you in your everyday life?", "Why did you select your topic for your analogy?", "Do you like using analogies?", and "Does protein synthesis create a picture in your mind?" (a copy of the questionnaire is in Appendix M).

In addition, fifty students from the researcher's class volunteered to be interviewed about their metacognitive processing during analogy use. It was an unstructured interview to allow the researcher to probe for the full meaning of the responses which typically results in more in-depth responses and "richer" data.The researcher interviewed fifteen students from the control group, twenty students from the student-generated group and fifteen students from the teacher-generated group. The researcher sought to obtain further information about the metacognitive processing during analogy use and student preferences for using analogies as an instructional tool (a copy of the interview questions can be found in Appendix N). Some of the questions were: " What do you think of when I say mitochondria?" "Explain, what comes to your mind next".

Data Analysis

Expertise/Novice. Students were classified as possessing either expert or novice content knowledge in science, based on their cognitive skill index score and their and local percentile score on the California Test of Basic Skills (CTBS) in science. For the purpose of this study, a student who obtained less than 75% in the local science score on the CTBS and achieved a cognitive skill index (CSI) score of 104 or less were considered novice, or a student with little science content knowledge. Students who achieved 76% or better on the CTBS science test and a cognitive skill index of 105 or greater were considered experts, or students that had a lot of science knowledge.

Correlations were conducted for all of the subtests and achievement measures to determine if a relationship existed between background variables and posttest achievement. The background variables were explored to delineate differences between the expert and novice science student. A multiple regression was performed to determine the relative contribution of prior knowledge and treatment in predicting the posttest scores.

Pretest/Posttest Scores. The scores from the multiple-choice pretest and posttests as well as the open-ended tests were examined for expert/novice differences. The difference between the means on the multiple-choice test were examined among the three groups and a repeated measures analysis was conducted to determine differences among the means in the immediate posttest and the 1-month posttest, using the pretest scores as the covariate. Since the students were not randomly assigned to the classes, the analysis included the pretest as a covariate to control for any differences between the classes in prior biology knowledge.

Open- ended Test. The differences among the means for the two questions were examined within the three groups of each teacher's class. A repeated measures analysis was conducted, covarying the prestest score for each question. The adjusted posttest means were compared for each question among the three groups. Expert/novice differences were also examined with all three questions.

Student Analogies. The students' analogies were categorized according to their selected topic and the type of similarity that they created. Topics were examined in terms of whether or not it was outside of the domain of science. Types of similarity were assessed by the number of relationships that were used to create the analogy. The student's work was classified as an anomaly, mere appearance, literal similarity or an analogy (a scoring form is in Appendix O).

Again, the student's analogy was considered an anomaly if it contained few attributes or relationships. A mere appearance contained mainly descriptors such as adjectives to describe the relationship between protein synthesis and the student's analogy. A literal similarity contained approximately an equal number of descriptive adjectives and active relationships (verbs) to describe the relationship between protein synthesis and the student's analogy. An analogy contained a majority of active relationships to describe the relationship between protein synthesis and the student's analogy. Differences were noted between experts and novices.

Questionnaires. The questionnaire data from the student-generated analogy group and the teacher-generated analogy group was qualitatively analyzed. The students' answers were examined in terms of student preferences for analogies, visual imagery created by analogies, associations created as a result of analogy use and metacognitive processing during analogy use. Differences were noted between expert and novice science students.

Interviews. Fifty students from the researcher's class were interviewed by the researcher to help flush out the metacognitive processing occurring during the use of analogies. The students were asked to reflect on the sequence of events that took place as they were asked questions that probed their knowledge and understanding of protein synthesis. Questions such as: "What is the first thing that you think of when ask you to give me the function of the mitochondria?" "Are you seeing a picture, if so,what is it?" (see Appendix N) were used to probe the student's understanding and processing of analogies. Metacognitive differences and similarities in student responses were analyzed according to expert/novice and treatment group. The interview questions attempted to assess whether a reorganization of knowledge occurred during analogy use, student preference for analogies, and the effectiveness of student-generated analogies.

Chapter 4

RESULTS

Introduction

The purpose of this study was to provide a comparative analysis of student performance of protein synthesis delivered by traditional science instruction, instruction with student-generated analogies, and instruction with teacher-generated analogies. This chapter presents the results of the study organized according to the research questions.

Research Question 1

Are student - and teacher-generated analogies more effective than traditional instruction in bringing about change in student understanding of a given scientific concept?

Multiple-choice posttest findings. Change in student understanding of protein synthesis was measured by the number of correct responses on a twenty question multiple-choice test and a two-question open-ended test that were taken immediately after the instruction and one-month after instruction. Change was measured by comparing the scores from the immediate and one-month posttest to the pretest. Student understanding was also measured by a short answer open-ended two question test taken immediately after instruction and one-month after instruction. Responses to the short answer open-ended questions were scored by two raters. Interrater agreement for the open-ended questions was high (97% agreement), indicating that the data was scored reliably.

Table 8 presents the means of the pretest, the multiple-choice test taken immediately after instruction and the multiple-choice test taken one month after instruction for each of the three treatment groups.

Table 8
Means and SD on the Multiple-Choice Pretest & Immediate and 1-month Test

		Pretest		First Posttest		Posttest (1 month)	
Group	n	M	SD	M	SD	M	SD
Control	89	9.61	2.91	12.27	3.48	9.67	3.64
Student-generated	92	10.50	2.62	13.37	3.01	11.56*	3.65
Teacher-generated	88	9.90	2.23	13.05	2.56	10.57	3.31

Note. Student-generated group performed significantly better at $p < .01$ level than the control group and the teacher-generated group on the one-month posttest.

A repeated measures analysis of covariance with the pretest as a covariate was performed to address these three questions: 1) was there an overall difference between the treatments, 2) was there a difference between the multiple-choice tests taken immediately and taken one-month after instruction, and 3) was there an interaction between the time the test was taken and the treatment ?

The results indicated that the pretest was significantly related to the posttests. The F-test for the covariate, the pretest, was significant F (2,263) = 5.98, p = .02. The F-test for the interaction between time of test and treatment was not significant F (2,264) = 1.37, p = .26, indicating that the difference between the treatment groups wasn't dependent on the time the test was taken. The scores were significantly higher on the immediate posttest scores. There was a significant loss in knowledge after one-month, regardless of treatment because there is a significant decrease in the student's posttest scores. The F-test for time the test was taken was siginificant, F (1, 264) = 150.37, p = .000.

This analysis used planned comparisons to examine differences between the three treatment groups. In experimental studies when the investigator has specific questions in mind, planned comparisons provide more power in detecting differences between groups than post-hoc analysis of all possible pairwise comparisons. In this study, three contrasts were tested: (a) a test of whether the average of the means at both time points was significantly different from zero, (b) a test of whether the control group means at both times were significantly different from the student-generated group, and (c) a test of whether the student-generated group means were significantly different from the teacher-generated means.

These planned comparisons were tested in the form of orthogonal contrasts using SPSS. The first contrast in (a) above was not relevant to the study, but was needed in the matrix of orthogonal contrasts.

The t-test for the contrast for the difference between the control and student-generated group was significant $\underline{t} = -2.98$, $\underline{p} = .003$. The t-test for the contrast of the difference between the student-generated and teacher-generated group was not significant $\underline{t} = 1.08$, $\underline{p} = .282$. Since the contrast between the student-generated and the control was significant, one can assume that the difference between the control and teacher-generated group is also significant since the student-generated group and the teacher-generated scores were not statisically significant.

Open-ended question findings. The students were also given an open-ended short answer test that consisted of two questions as a pretest, immediately after instruction and one-month after instruction. The first question was a two-part question.The questions were 1a) "What is a protein?" , 1b) "Why are proteins important?", and question 2) "How are proteins made in the body?" Questions 1a and 1b tested general knowledge about proteins, and question two examined the student's understanding of how proteins were made. These questions were scored on a scale of 0-4, with a score of zero representing no understanding and a score of 4 representing complete understanding of protein synthesis. A score of one, two or three represented varying degrees of understanding. The means and standard deviations of the pretest, the immediate posttest and the one-month posttest for the three groups for the two questions can be found in Table 9.

Table 9

Means and SD of Open-Ended Questions

			Pretest		Posttest (Immediate)		Posttest (1-month)	
Group	Question #	n	M	SD	M	SD	M	SD
Control	1a	89	1.47	1.34	2.16	1.99	1.94	1.97
Student-generated	1a	92	1.80	1.29	1.97	1.67	1.98	1.76
Teacher-generated	1a	88	1.58	1.29	2.08	1.59	2.00	2.73
Control	1b	89	2.64	1.70	3.51	1.62	3.64	3.56
Student-generated	1b	92	3.07	1.27	3.47	1.37	3.71	1.38
Teacher-generated	1b	88	2.85	1.36	3.72	1.11	3.54	1.36
Control	2	89	2.55	1.75	2.55	1.75	2.40	1.76
Student-generated	2	92	2.09	1.25	3.26	1.97	3.20	1.86
Teacher-generated	2	88	1.58	1.31	3.30	1.71	2.95	1.76

A repeated measures analysis was done using the pretest as the covariate. A repeated measures was performed to assess whether 1) there was an overall difference between the treatment groups, 2) there was a difference between the immediate and posttest questions, and 3) whether there was an interaction between the time the test was taken and the treatment. The repeated measures analysis indicated that there was a difference between the control group and the two experimental groups, in that the experimental groups outperformed the control group only on the second question. There was no significant difference in terms of time (pre- and posttest) and no significant interaction between treatment and time.

Question number 1a was: " What are proteins?" There was a significant relationship between the pretest and posttests. The F-test for the covariate (pretest) was significant *F* (1, 263) = 22.09, *p* = .000. The difference between the treatment groups didn't depend on the time the test was taken. The F-test for the interaction between the time the test was taken and treatment was not significant , *F* (2, 264) = .441, *p* =.647. There were no significant differences between the groups for this question.The F-test for treatment was not significant *F* (2, 263) = .312, *p* =.734. There was not a significant loss of knowledge over time, regardless of the treatment. The F-test for the time the test was taken was not significant *F* (1, 264) = 1.03, *p* = .311.

Question number 1b was: " Why are proteins important in our lives?" There was a significant relationship between the pretest and posttest. The F-test for the covariate, the pretest, was significant *F* (1, 263) = 22.64, *p* = .000. The F-test for the interaction between time of test and treatment was not significant *F* (2,263) = 1.37, *p* =.26, indicating that the difference between the treatment groups didn't depend on the time the test was taken. The difference between the posttest scores was not related to the group that the students were assigned. The F-test for treatment was not significant *F* (2, 263) = .12, *p* = .891.

There wasn't a loss of knowledge after one-month regardless of the treatment. The F-test for time was not significant _F_ (1,264) = .81, _p_ = .445.

Question number two directly addressed the use of analogies. The question was "How are proteins made in the body?" Both the student-generated analogies and the teacher-generated analogies directly involved the process of protein synthesis. The F-test for the covariate, the pretest, was significant _F_ (1,263) = 21.96 , _p_ =.000. The difference between the treatment groups didn't depend on the time that the test was taken. The F-test for the interaction between time of test and treatment was not significant _F_ (2, 264) = 1.49 , _p_ = .227. Both the student-generated analogies and the teacher-generated analogy improved student performance on this question. The time that the test was taken didn't influence the posttest scores. The F -test for the time the test was taken was not significant _F_ (1, 264), _p_ = .118. The results indicated that there was a significant difference between the treatments _F_ (2,263) = 5.58 , _p_ =.004.

The same planned comparisons were used in this analysis described earlier. The t-test for the contrast for the difference between the control and student-generated group was significant , _t_ =-3.10 , _p_ = .002 . The t-test for the contrast of the difference between the student-generated and teacher-generated group was not significant, _t_ = -.507 , _p_ = .613.

In summary, the student-generated group and teacher-generated group outperformed the control group on the second question. The second question was a question that addressed the core instructional material of the unit, the process of protein synthesis. This question directly probed the effectiveness of the instructional use of analogies.

Interview findings. The superior performance on the multiple-choice test by the student-generated analogy group can be partially explained by the student responses on the interview.

Fifty students (twenty-five from each group), the student-generated analogy group, and the teacher-generated analogy group were interviewed one-month after the unit about their perspective on using analogies. Students were first asked to recall the function of the mitochondria, a review organelle, or cellular physiology. They were asked to describe exactly what they were thinking or visualizing in a sequential manner. The students were asked to respond in a similar manner for the other two questions about protein synthesis. Responses to the interview indicated that the student's level of understanding of protein synthesis seems to be dependent on the method of instruction that they received. When asked to describe protein synthesis, students in all three groups created a visual image ; however, the created image was based on the type of instruction that the students received. The type of visual imagery could explain the difference in performance on the multiple-choice tests between the groups.

The control group retrieved fragments of general knowledge about proteins that was indicative of an incomplete understanding and fragments of the instructional drawing that was used to review cell physiology. The student-generated analogy group created a visual image of their analogy and the process of something being made. The teacher-generated group created a variety of visual images. Some of the images were consistent with the analogy provided by the instructor, while others consisted of fragments of general knowledge about proteins from the instructional drawing. The following are examples of responses by each of the treatment groups to the interview questions.

Interview Question: What is the first thing that comes to mind when I say "protein synthesis"?

Control Group:

Dave: . . . a long complicated process.

Leslie: . . . I think of something being made.

Nick: . . . the picture of the cell that we drew.

Solly: . . . I don't know, that proteins are important for us.

Chris: . . . they make our fingernails grow.

Student-Generated Group:

Lisa: . . . a picture of the cell and the processes.

Heather: . . . my analogy.

Hanna: . . . computers because they speak a language.

Kelly: . . . my analogy of my family.

Steve: . . . a little factory.

Isiah: . . . genetics and Jurassic Park.

Todd: . . . a city because that's how I did my analogy.

Teacher-Generated:

Stephanie: . . . the analogy of the principal and the message.

Clare: . . . a message being delivered to someone.

Danielle: . . . a messenger doing its job.

Stacey: . . . sending a message to my friends.

Kate: . . . DNA, mRNA.

Lauren: . . . a long complicated process.

In summary, the control group recalled the instructional drawing of cell physiology and fragments of general knowledge about proteins. The students that had generated their own analogy of protein synthesis recalled the drawing of their analogy. All of the students, regardless of the treatment group assigned, stated that if a picture wasn't provided with an analogy, they automatically created one on their own. The students in the teacher-generated group, who scored high on the pre-tests, were able to recall the analogy of the principal and the school; whereas, the students who scored low on the pre-tests, seemed to provide more random, incoherent ideas. This could be due to the possibility that the students didn't understand the teacher's analogy.

In addition to the different type of visual imagery that took place during the understanding of protein synthesis, student preference for analogies could also explain their better performance on the one-month posttests. Fifty students from the student-generated group and teacher-generated groups were interviewed about their perceived usefulness of analogies.

Ninety-nine percent of the students stated that the analogies were helpful in trying to understand difficult scientific material. Overall, it seems as though males preferred student-generated analogies whereas females preferred teacher-generated analogies, as shown in Table 10. Incidentally, it is interesting that there seems to be a gender difference in terms of analogy preference.

Table 10
Percentage of Student Preference by Gender

	Gender	
Type of Analogy	Females	Males
Student-generated analogies	30%	64%
Teacher-generated analogies	60%	30%
Both	10%	6%

In addition to examining overall student preference and gender preferences for analogical use, preference differences were noted between the two ability groups.The students that had more general science knowledge preferred student-generated analogies; whereas the students with less general science knowledge preferred teacher-generated analogies.

High Ability Science Students. High ability students were students who scored above the seventy-fifth percentile on the local CTBS test and obtained a cognitive skill index of at least 105. The majority of the high ability students agreed that student-generated analogies were more helpful than teacher-generated analogies as shown in Table11 .

Table 11
Percent of Preference Between High/Low Ability Science Students

	Science Ability of Student	
Type of Analogy	High Ability	Low Ability
Student Analogies	84%	53%
Teacher Analogies	15 %	39%
Both	1%	8%

The students stated that student-generated analogies are much more meaningful because the student selects a topic that they are interested in and therefore, it is more meaningful to them. They also stated that sometimes students don't understand the teacher's analogies; in fact, in many cases it can be more confusing. They also claimed that student-generated analogies were easier, more fun, and more interesting. The students were cognizant of the fact that they have different interests than the teacher. The same high science students; however, preferred the teacher-generated analogies because they believed that the teacher knows more about the topic; therefore, they have a better understanding and their analogies will be more scientifically correct. They didn't have a lot of confidence in their own analogies. It is interesting to note the group that preferred teacher-generated analogies consisted of all females. Some examples of their responses were as follows:

Paul: . . . student-generated, because they are our own ideas.

John: . . . student-generated because you remember what you have made. Teacher analogies are just another thing to cram into your head.

Kanishka: . . . student-generated because we can understand it in our own way.

Rick: . . . student-generated because we are more familar with our lives and mind than teachers are.

Erich: . . . student-generated because we like different stuff than the teacher; therefore, ours are more interesting and fun.

Marcy: . . . teacher-generated because they know more and can make the right ones.

Erin: . . . teacher-generated because teachers have more scientific knowledge.

Angie: . . . teacher-generated because teachers have a better understanding and theirs are more effective.

Low Ability Science Students. Low science students were students who scored below the seventy-fifth local percentile on the CTBS and obtained a cognitive skill index of 104 or less. The low ability science students (regardless of gender), were unanimous in that they liked using analogies (both student and teacher -generated) because they were fun,interesting and easier; however, more selected student -generated analogies. The low ability science students felt that if it wouldn't have been for the use of analogies, that they would've never understood the scientific material. Examples of their responses were as follows:

Kevin: . . . student-generated are better because you are set to use it yourself.

Dan: . . . student-generated because you don't always understand the teacher's topic.

Dave: . . . student-generated because we can pick what we like.

Julie: . . . student-generated because the analogies are in our own words.

In summary, the most effective method of instruction for protein synthesis seems to be to have the students generate their own analogies about the topic. Analogies provoke a powerful imaging process that makes the acquired knowledge readily available to the students. This powerful visual imaging process is contributing to the better performance on the one-month multiple-choice test by the student-generated analogy group.

The students that have more general science knowledge prefer to generate their own analogies and seem to benefit more from this type of instruction. When the students generate their own analogies, they visualize the entire analogy that they created as opposed to fragments of information that the control group and teacher-generated group visualized. The generation of an analogy from an already familar topic coupled with a high student interest and a more complete visualization of the process of protein synthesis is allowing students to conceptually reorganize their knowledge into new, more meaningful schema.

Research Question 2a

What is the nature of the change? How are student-generated and teacher-generated analogies related to the student's subject matter knowledge?

Correlations were conducted for all of the subtest and achievement measures to determine if a relationship existed between prior knowledge in science and posttest achievement as shown in Table 12.

Table 12
Intercorrelations Among Background Variables

Variable	1	2	3	4	5	6	7	8	9
1. Age	1.00								
2. Biology pretest	-0.07	1.00							
3. CSI	-0.08	.31*	1.00						
4. CTBS- NP	-0.06	.35*	-.07	1.00					
5. CTBS- LP	-0.05	.40*	.14	.92	1.00				
6. MC Posttest	-0.03	.45*	.14	.44	.39	1.00			
7. MC-1month	-0.14	.42*	.06	.34	.36	.60*	1.00		
8. Open-end-2(i)	-0.08	.42*	.10	.34	.29	.27	.40	1.00	
9. Open-end-2(1)	-0.11	.40*	.17	.32	.31	.41	.50	.61*	1.00

Note. CSI= cognitive skill index, CTBS= California Test of Basic Skills, MC= Multiple Choice Test, Open-ended question test, i= immediate, 1=1 month, 2= question number.

There are several significant correlations between the Biology Pretest, the CSI (cognitive skill index) score and the CTBS percentiles (both local and national percentiles). These factors were used to explore the relationship between prior knowledge and posttest results. There is also a significant relationship between the multiple-choice pretest and the posttests.

A multiple regression was performed to assess the relationship between prior knowledge and posttest results. Two regression analyses were performed on the background variables and the pretest to determine how they were related to the posttest scores on the multiple-choice test (immediate and one-month). There were also two dummy variables: T (1) took the value one for all students in the student-generated group and zero otherwise, and T (2) took the value one for all students in the teacher-generated group and zero otherwise. The coefficient for T (1)will be the estimate of the average difference in posttest scores between the student -generated group and control, while the coefficient for T (2) will be the estimate for the average difference between teacher-generated and control, while controlling for the other variables in the model.

Table 13
Multiple Regression with Immediate Posttest Score as Dependent Variable

Variable	Coefficient	Standard Error	Standard Coefficient	p
Constant	10.464	0.550	0.000	0.000
Biopretest	-0.046	0.017	-0.154	0.007*
CSI	0.004	0.003	0 .075	0.189
CTBSLP	0.044	0.007	0 .375	0.000*
T1 (Student)	0.329	0.453	0 .048	0.468
T2 (Teacher)	0.213	0.453	0 .031	0.639

Note. CTBS-local percentile and the Biopretest (biology pretest) were the two variables that contributed significantly to the posttest results. CSI= cognitive skill index,, T1=a dummy variable created for the student-generated group, T2= a dummy variable created for the teacher-generated group.

The regression analysis in Table 13 produced an adjusted R square of .43. Forty-three percent of the variance for the immediate posttest was explained by the model. The pretest was significant in the equation. It was negatively related to the immediate posttest score. The estimate for the coefficient for the pretest was statistically significant, though it was negatively related to the posttest score. This result might be due to the fact that the pretest has a significant correlation with all other predictors in the equation.

The CTBS- local percentile was also a significant predictor in the equation. Students with larger values of CTBS-local percentile tended to have higher scores on the immediate posttest.

The two dummy variables gave an estimate of the predicted difference between treatment groups which controlled for all other variables in the equation. Controlling for the pretest scores and prior knowledge from the CTBS-local percentile scores seems to eliminate the difference between the treatment groups. The coefficients for the two dummy variables were not significant when controlling for the pretest and background knowledge, indicating that the difference between the treatment groups and control were not different from zero when prior knowledge is taken into account.

A second multiple regression analysis was done to assess the relationship between prior knowledge and the posttest score taken one-month after instruction, see Table 14. This multiple regression produced an adjusted R squared of .39 .

Thirty-nine percent of the variance on the one-month posttest was explained by the regression model. Two predictor variables were significant in the analysis for the one-month posttest. Again, the CTBS-local percentile score is a significant predictor in the equation. Students with larger values of CTBS-local percentile tend to have higher scores on the one-month posttest. However, the dummy variable comparing the student-generated analogy group to the control group was significant. Even controlling for differences in background knowledge, the student-generated group was predicted to score higher an average of .99 points higher than the control group on the 1-month posttest.

Table 14
Multiple Regression with the 1-Month Posttest as Dependent Variable

Variable	Coefficient	Standard Errror	Standard Coefficient	p
Constant	8.119	0.629	0.000	0.000
Biopretest	-0.032	0.019	-0.097	0.092
CSI	0.001	0.004	0.008	0.888
CTBSLP	0.045	0.008	0.343	0.000*
T1	0.990	0.518	0.129	0.050*
T2	0.328	0.519	0.042	0.528

Note. Biopretest (biology pretest), CSI (cognitive skill index), CTBSLP (California Test of Basic Skills-local percentile), T1 a dummy variable created for the student-generated group, T2 a dummy variable created for the teacher-generated group. * CTBS-LP and T 1 are significant predictors of the one-month posttest scores.

The other dummy variable (T2) comparing the performance on the one-month posttest of the teacher-generated group to the control group was not significant. Controlling for background variables, there was no difference between the teacher-generated analogy group and the control group. In summary, it seems as though the student-generated group scores about one point higher on the one-month posttest than the control group even when background knowledge is taken into account.

The relationship between prior subject matter knowledge and success with student-generated analogies is further supported by evidence from student interviews. It also seems that there are other differences that exist between the successful use of analogies and the cognitive ability of the learner. Interviews with students suggest some differences between the ability groups on the topic selected for the creation of their analogies.

Fifty students were interviewed about their metacognitive processing during analogy use. Twenty-five of the students were considered novices based on their cognitive skill index score and their local percentile score on the California Test of Basic Skills in *science*. A student was defined as “low ability” if they obtained less than 75 % in the local science on the CTBS and also achieved a cognitive skill index score of 104 or less. The remaining twenty-five students were considered high ability science students if they had a score of 76% or better score on the CTBS science test and obtained a cognitive index score of 105 or more.

The majority of the students (80%) selected or accessed a far domain (non science content area) over a near domain (20%) in a science related content area. Examples of topics that were selected from a far domain are: shopping, city, factory, mail delivery system, war, tailor's shop, a river system, lawyer's job, family interactions,etc. Examples of topics selected from a near domain or a science-related field include: computers, and construction sites.

High Ability Science Students. Interviews of the students reflect some general tendencies in the selection of their topic for creating their analogies. Ninety-five percent of the high ability students indicated that they selected their topic because it contained a similar function or relationship as the stages of protein synthesis. Samples of the student responses regarding their topic choices were grouped according to the amount of science knowledge as follows:

> Liz: . . . I picked my topic because of the similar function. If I had picked a topic because of how it looked, it would've mixed me up because most of the time it didn't really look like anything, so it didn't make sense.
>
> Elena: . . .I selected my analogy because of what it did, because nothing is really exact with the picture.
>
> Lisa: . . . I picked a factory because it seemed like protein synthesis because they both work to create something.
>
> Julia: . . . it reads codes and we read books.
>
> Eiketsu: . . .because it clearly made an image of protein synthesis.
>
> Todd: . . . because I knew a lot about cities . . . therefore it was easy to plug in protein synthesis and how it operates.

Nick: . . . the process of constructing something, because my dad does construction work.

Paul: . . . it seemed the most similar because of how it operated.

The high ability science students stated that they would research the topic or try to really understand the topic before selecting a topic from which to create their analogy. They were trying to map the components of protein synthesis according to similar functions or structural relationships in another domain.

The students that received the student-generated analogy approach were predicted to perform better on the posttest scores one-month after instruction than the other two groups. In summary, it seems as though the students who bring more general science background knowledge with them to science class, benefit most from the student-generated analogy approach. Differences existed between students with a lot of science knowledge and the students with less knowledge in science in their selection of topics. The students with more science knowledge selected their topics for their analogies based on similar relationships or actions. The students with less science knowledge selected their topics based on a blend of relationships (the use of verbs) and descriptors (the use of nouns and adjectives) or surface features in the construction and description of their analogies.

Research Question 2b

How do the subprocesses of analogical reasoning in expert and novice science students compare?

Accessing An Analogy. Twenty-five students from the student-generated group and twenty-five students from the teacher-generated groups were interviewed six weeks after they had received the protein synthesis instruction to determine what they remembered six weeks following instruction. Students from all three groups were asked 3 questions, which will be discussed in this section. The three questions were : 1) What is the function of the mitochondria, 2) What is the first thing that comes to your mind when you hear "protein synthesis?" and 3) Does protein synthesis create a picture in your mind? The first question was asked to assess the student's long-term memory of the topic and examined cognitive retreival of isolated facts about protein synthesis; the second question was asked to determine whether the auditory prompt of protein synthesis created a visual image and cognitive retreival of concepts; and the third question was to determine whether the verbal component or the visual imaging of the analogy was more important in understanding protein synthesis.

Interview Question 1 : What is the function of the mitochondria?

Many of the students claimed that the first thing that "came" to mind was the instructional drawing of protein synthesis. All three of the groups received the drawing of the cell as part of the introduction to protein synthesis (Appendix

P). The low ability students accessed the entire picture then scanned the picture looking for the specific organelle in question. The high ability students had developed strategies to specifically "zero in" on the organelle in question as demonstrated in the responses below. There was a significant difference between the control group and the experimental groups in their method of retreiving facts about protein synthesis.

High Science Ability Responses: (Both student and teacher-generated groups)

Brenden: . . . I see the big M & M's because we drew the picture in class.

Brandon: . . . I first recalled the zigzag" structure of the mitochondria.

Lisa: . . . I first recalled the "zigzag" lines on the circle.

Liz: . . . I see a picture of a beehive, specifically. I think of it as a beehive, then I think of the behive as the powerhouse.

Kim: . . . I remember first the "W" on the circular drawing of the mitochondria.

Low Science Ability Responses: (Both student and teacher-generated groups)

Michelle: . . . I first recalled the big picture of the cell.

Syveda: . . . I don't remember, I am picturing the cell and I can't find it. I tried the ribosomes and endoplasmic reticulum, it's like a snake because of the way it is shaped and the ribosomes are the 'bumps'.

Christina: . . . I created a picture of the things that surround the mitochondria.

Katie: . . . I pictured the drawing of the entire cell first.

Dana: . . . I see the big picture, it stuck in my head . . . then I focused on the little picture of the mitochondria.

In summary, when the students were asked to retreive information about a specific fact or piece of information, the high ability students seemed to have a strategy for focusing directly on the organelle in question; whereas, the low ability students first "scanned" the entire drawing looking for the mitochondria before making the cognitive connection to the function of the organelle. See Figure 8 for a detailed description. It is interesting, however, that regardless of ability, or treatment group, both groups visualized the image of the cell when prompted by an auditory question.

In addition to examining how students retreived pieces of factual information regarding protein synthesis, concept retreival was also examined. The premise for this research was that analogies would be beneficial for reorganization of knowledge; therefore; the students would be able to retreive a better conceptual understanding of the topic if they had used analogies. The second interview question addressed concept understanding. The student responses were categorized according to ability level.

Interview Question 2 : What is the first thing that comes to mind when I say "protein synthesis"?

Control Group/ High Science Ability:

Dave: . . . a long complicated process.

Nick: . . . the picture of the cell that we drew.

Control Group/Low Science Ability:

Solly: . . . I don't know, that proteins are important for us.

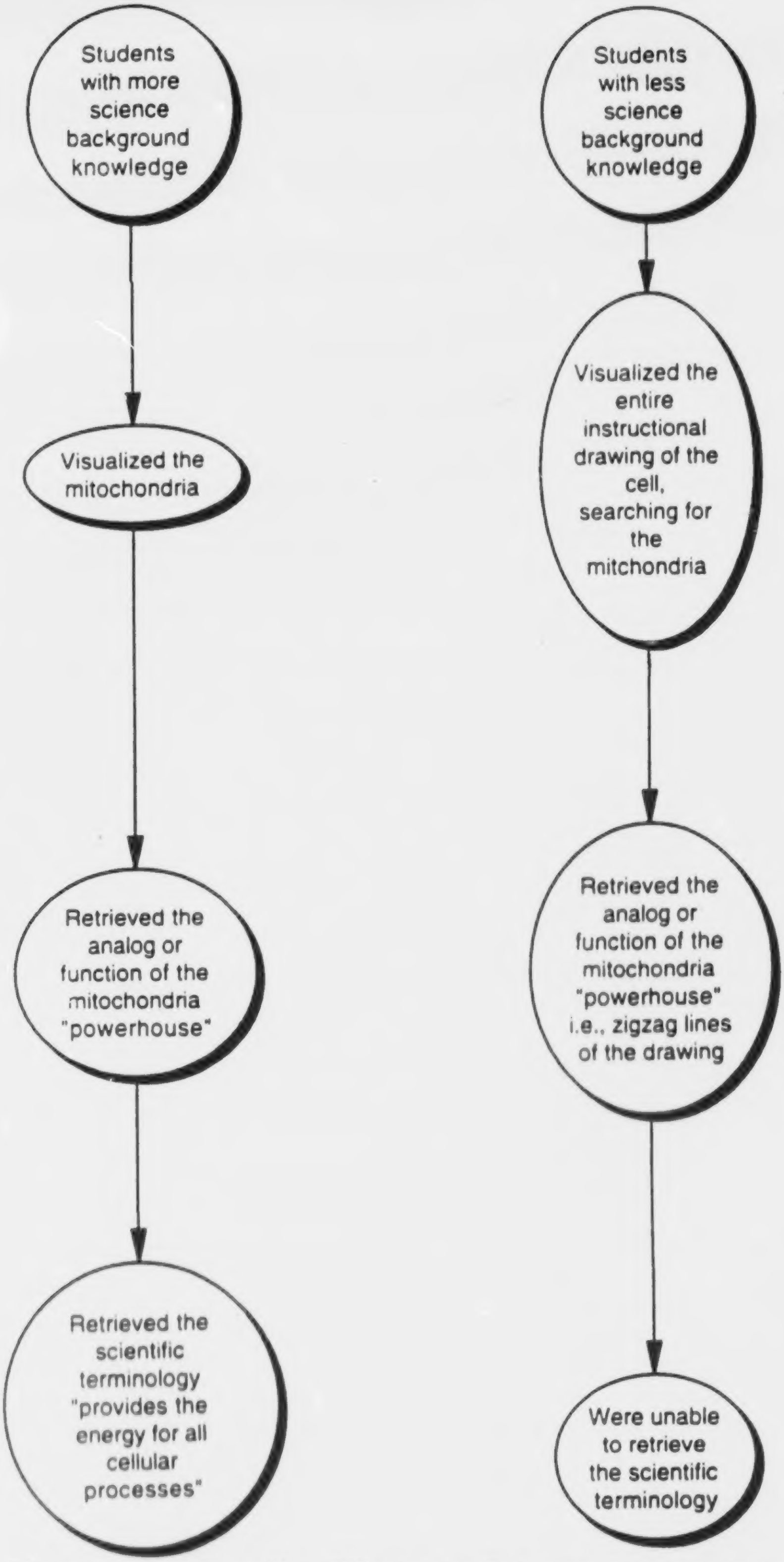

Students with more science background knowledge
Visualized the mitochondria
Retrieved the analog or function of the mitochondria "powerhouse"
Retrieved the scientific terminology "provides the energy for all cellular processes"
Students with less science background knowledge
Visualized the entire instructional drawing of the cell, searching for the mitchondria
Retrieved the analog or function of the mitochondria "powerhouse" i.e., zigzag lines of the drawing
Were unable to retrieve the scientific terminology

Figure 2. Metacognitive Differences Between Science Ability Groups

Chris: . . . they make our fingernails grow.

Student-Generated Group/ High Science Ability:

Lisa: . . . I picture the cell and the processes.

Heather: . . . my analogy.

Hanna: . . . computers because they speak a language which needs to be translated.

Student-Generated/Low Science Ability:

Kelly: . . . my analogy of my family.

Steve: . . . a little factory.

Isiah: . . . genetics and Jurassic Park.

Todd: . . . a city because that's how I did my analogy.

Teacher-Generated/ High Science Ability:

Stephanie: . . . the analogy of the principal and the message.

Clare: . . . a message being delivered to someone.

Danielle: . . . a messenger doing its job.

Stacey: . . . sending a message to my friends.

Teacher-Generated/ Low Science Ability:

Kate: . . . DNA, mRNA.

Lauren: . . . a long complicated process.

Generally, the students that had generated their own analogy of protein synthesis stated that they recalled the drawing of their analogy. Both groups, student-generated and teacher-generated, reported that the "picture" was the association that was retreived initially. All of the students stated that if a picture wasn't provided with an analogy that they automatically created one on their own. The students in the teacher-generated group of high ability were able to recall the analogy of the principal and the school; whereas, the low ability science students seemed to provide more random, incoherent ideas. This could be due to the possibility that the students didn't understand the teacher's analogy.

Also, the high ability science students in all three groups were able to explain "aprocess", whereas the low ability science students from all three groups described more declarative knowledge or fragments of information about protein synthesis.

Some differences did exist between the student-generated group and the teacher-generated group. The student-generated group was more apt to retreive the drawing of their own analogy; however, they also retreived the illustration used during instruction. The teacher-generated group immediately and consistently accessed the instructional illustration (see Appendix P), followed by the school analogy.

Other differences existed in the access of protein synthesis between the low and high ability science students. The high ability science students had a more efficient access to the question directly at hand. These high ability students were able to directly focus on the image of the instructional drawing that they needed to upon an auditory prompt. The low ability science students also immediately accessed the visual image of the cell; however, they had to first scan the drawing in their mind to findthe image that the high ability science students were able to immediately access (See Figure 2). After both groups of students located the visual image of the organelle, they both retreived the scientific word associated with it (i.e., mitochondria). Attached to the visual image for both groups was the analog of the word (i.e., "powerhouse" for mitochondria). Another difference occurred between the two groups. The high ability science students were able to recall the scientific definition of the meaning of the analog, or "powerhouse"; whereas the low ability science students were unable to recall the scientific meaning.

Interview Question # 3: Does protein synthesis create a "picture" in your mind?

The same students were interviewed and asked if protein synthesis created a "picture" in their mind when they asked to explain it. The results from the first and second interview questions revealed a visual imagery taking place, so this question was asked to probe at the specifics of the visual imagery. The results indicate that regardless of ability, the students consistently accessed a visual image upon an auditory prompt. The teacher asked, "if I ask you to explain protein synthesis, does it immediately create a picture in your mind?"

High Ability Science Students

Amy: . . . yes, a cell producing protein.

Katie: . . . a cell and DNA unzipping.

Caroline: . . . yes, the picture that we drew together in class.

Kate: . . . yes, my analogy, a machine with every part doing its job.

Stacey: . . . yes, a school (teacher's analogy) and the cell model that we made at the beginning of the year.

Lisa: . . . yes, I see the picture that I drew of the cell and the three processes taking place.

Tim: . . . yes, computer games.

Young: . . . yes, little things moving in a cell.

Low Ability Science Students:

Rachel: . . . yes, a house and a city working together.

Eva: . . . yes, my analogy of an office building and everybody working together.

A summary of the type of visual imagery created is shown in Table 15.

Table 15
Type of Visual Image Created Upon Accessing an Analogy

Student Ability	Control	Student-generated	Teacher-generated
High Ability	cell drawing from instruction	the image of their analogy	the school analogy
Low Ability	cell drawing from instruction	cell drawing from instruction	cell drawing from instruction

This visualization of events that the students transferred can be characterized by following a sequence of responses from the pretest through the construction of the analogy to the posttest of Student X. Student X was a high ability male student who mastered the concepts of protein synthesis. Student X's answers to the pretest version of the preconceptions test can be found in Appendix Q. The student's answers were clearly erroneous and the student admitted that he had "no clue". A description of this students analogy is in Appendix R, as well as an illustration of the analogy that he constructed, titled, "Rebel Forces Need Supplies". This student selected the topic of war from a far domain (one outside of science) and his topic was stereotypically a male topic.

Examination of the steps in the creation of the analogy revealed some interesting ideas. The student initially broke down the process into nine components and used in his description of the steps, verbs or structural features (i.e., makes, takes, goes, reads, delivers, stops, used, etc.) (Appendix S). Gentner (1989) , claims that the use of verbs to explain analogies has more inferential power in learning. The student then proceeded to attach a noun (surface feature) to the scientific terminology (i.e., amino acids are guns, proteins are supplies, hydrogen bonds are meeting places, mRNA is the first spy, etc.). After the student had attempted to understand the process of protein synthesis, he illustrated his analogy with seven steps as shown in Appendix T. When this illustration was compared to his open-ended posttest taken one month later (Appendix T), the transfer of the cylindrical shape of the endoplasmic reticulum to step three was symbolically evident (see Appendix T). The retention of the same number of steps was also interesting, as well as the drawing provided for question number one in Appendix T. According to Gentner (1989), this student created a true analogy because of the frequent verb usage to describe the similarity between the analogy and protein synthesis. This student clearly mastered the concept of protein synthesis.

In summary, a visual image was immediately retrieved upon an auditory prompt from both low ability and high ability science students. The low ability science students recalled the instructional drawing that they created with the instructor as an introduction to protein synthesis. The intent of the drawing was to review the cellular organelles before applying the process of protein synthesis to cellular physiology. It seems that the low ability science students had mastered the basic components and physiology of the cell but not details of protein synthesis in the form of an analogy. The high ability science students were able to replace their initial image of the cell with the analogy. The difficulty of the material involved with protein synthesis could explain the difference between the two groups. This is also supported by the evidence of the differences between the low and high ability science students in how they access an answer for an auditory prompt.These differences in access also suggest differences in conceptual reorganization between the two groups. The high ability science students are linking the new information into more efficient meaningful schema.

Mapping Analogies. The analogies of protein synthesis constructed by the fifty students were also analyzed for mapping features. Mapping was looked at to determine how the accessed knowledge was linked to existing schema or involved in the creation of new schema. The analogies were mapped or linked by either descriptors (nouns) or verbs. Student understanding was measured by analyzing the analogies created by the students using an analogy score sheet (Appendix O) that characterized analogies according to Vosinadou (1989) and Gentner (1991). Another science teacher scored the student's work and interrater reliabilty was 0.92.

Once the students selected their topics, they had to assign words or descriptors to explain how the components of their analogies were related to protein synthesis.The student's analogies were categorized according to the type of similarity that they created and the words or descriptors that the student used to create their analogy (Gentner, 1990), and the topic selected for the analogy (Vosniadou, 1989).The type of similarity between the student's conceptualization and protein synthesis produced was classified according to Gentner (1990) as: an anomaly, mere appearance, literal similarity or an analogy. These types of similarities were based on the presence of attributes (nouns, adjectives) and the presence of relationships (transitive verbs, comparative adjectives and prepositions) used to characterize the analogy. A mere appearance contained descriptive relationships, a literal similarity contained some descriptive and some action words and an analogy contained action relationships.

A student's analogy was considered an anomaly if it contained few attributes or relationships (i.e., Coffee is like the solar system). A mere appearance contained mainly descriptors such as adjectives to describe the relationship between protein synthesis and the student's analogy (i.e., The glass tabletop gleamed like water.) A literal similarity contained some descriptive adjectives and some active relationships to describe the relationship between protein synthesis and the student's analogy (i.e., Milk is like water). An analogy contained many active relationships to describe the relationship between protein synthesis and the student's analogy (i.e., Heat is like water).

Of the high ability science students, sixty percent of the students created true analogies that involved mapping structural or relational features (Appendixes U & V). The second most frequent type of similarity created by high ability students was a literal similarity (Appendixes W & X) which used both structural / relational (i.e., verbs) components as well as surface features (i.e., nouns / adjectives) as shown in Table 16.

Table 16
Percents of theType of Similarity Mapped

Type of Similarity	n	High Ability	Low Ability
Anomaly	1	1.0%	0.0%
Mere Appearance	17	9.7%	14.2%
Literal Similarity	21	30.0%	50.0%
Analogy	37	60.3%	34.8%

Low Ability Science Students. There was a significant difference between the high ability and low ability science students in the type of similarity generated from the student-generated analogy instructional method. Unlike the high ability students, the low ability students indicated that they selected topics because of both the surface features (i.e.,nouns, adjectives), and sometimes structural features (i. e., verbs). One student, stated that they selected their topic because " it looked like my room, or a string of beads, etc.". (See Appendixes Y & Z for examples of literal similarities)

Unlike the high ability students, the low ability students could only recall the surface features of protein synthesis. This is also supported by the fact that they generally created more literal similarities which relied on surface features. They could not recall the scientific explanation for the content in question.

When the low ability science students were asked why they selected their topic to create their analogy, the interviews showed that many of them selected their topic because it physically resembled something that they had familarity with. Some examples of their responses were as follows:

> Rachael: . . . it was the first thing that came to mind.
>
> Angie: . . . shopping is an important part of my life . . . it reminded me of how a shopping mall looks.
>
> Brett: . . . it was easy and fun because I play basketball, I used the players and their positions on the court.
>
> Judy : . . . it looked like it.
>
> John: . . . it was the picture that popped into my mind.
>
> Keith: . . . I know soccer best and so the set up of the field reminds me of protein synthesis.

Overall, irregardless of ability, females created more analogies as shown in the following Table 17.

Table 17
Type of Similarity by Gender

		Gender	
		Female	Male
Type of Similarity	n	n	n
Anomaly	1	0	1
Mere Appearance	17	9	8
Literal Similarity	21	9	12
Analogy	37	21	16

In summary, the multiple regression analysis indicated that the student-generated analogy group was predicted to perform better on the one-month posttest. In addition, the students that brought more science knowledge to the task would benefit more from student-generated analogy instruction. The interviews corroborate this in that, the high ability students selected their topics because of a similarity in function to protein synthesis and hence, used more relationships or verbs to construct their analogies, resulting in the construction of a true analogy. The use of relationships and a familar topic allowed for conceptual reorganization of the new knowledge in the development of new schema. The differences in schema are evident in the efficient access patterns of the high ability science students.

In contrast, the low ability science students selected their topics based on similar structure and function, hence, used descriptors or nouns and adjectives more frequently than the high ability students. However, the low ability students in the student-generated group produced as many true analogies as literal similarities. In spite of this, the students with less science knowledge demonstrated a different access pattern than the students with more science knowledge; which resulted in a difference in mapping patterns of their analogy.

Chapter 5

DISCUSSION

This chapter presents a discussion of the findings of the study, conclusions and recommendations for further research. The researcher set out to explore the phenomenon of analogy use in two eighth grade biology classrooms. The relationship between analogies, alternative conceptions, student ability and the subprocesses of analogical reasoning ability will be discussed. The role of analogies in the learning process will be analyzed from a constructivist perspective. The two research questions were:

1) Are teacher and student-generated analogies more effective than traditional instruction in bringing about change in students' understanding of a given scientific concept?

2) What is the nature of the change?

   a. How are student-generated and teacher-generated analogies related to the students' subject matter knowledge?

   b. How do the subprocesses of analogical reasoning in expert and novice science students compare?

Introduction

The rationale for this study was based on the following argument: Because of the unstructured learning of many situations outside of school contexts (especially in contrast to traditional instructional contexts), students need to develop the ability to identify and represent scientific phenomena in a manner that enables them to gain a greater understanding on their own. Science instruction, therefore, should enable students to identify and work on problems with a minimum of reliance on teacher guidance and instructional cues, and with a maximum emphasis on bringing to bear their own existing knowledge about the particular phenomenon. In this study, student-generated and teacher-generated analogies were investigated as a tool by which individuals could construct-largely on their own-better accounts of scientific phenomena.

In instructional situations, the analogy is typically constructed by a knowledgeable individual (teacher) and is used as a means to represent a concept to those who are less knowledgeable (students). Studies demonstrating or exploring the power of instructional analogies have varied in their emphasis from using analogies to overcome student misconceptions (Clement, 1987; Stavy, 1991), to analogies as an aid to comprehension and memory when reading text (Halpern, 1990), to general discussions on the benefits of analogies in instruction (Duit, 1991).

In each of these studies, analogies were provided by an outside authority- the role of the student was to make sense of the received analogy. Individuals had minimal responsibility for representing the scientific phenomenon in their own terms. Although these studies provided important evidence that analogies did facilitate learning and understanding, they did not suggest that student-generated analogies might be of value.

Research Question 1

Are teacher and student-generated analogies more effective than traditional instruction in bringing about change in students' understanding of a given scientific concept?

The first research question was generated to investigate whether student performance would increase as a result of the utilization of nontraditional instructional methods in science, specifically the use of teacher-generated analogies and student-generated analogies. The results of this study suggest that traditional science instruction of protein synthesis wasn't as effective as instruction with analogies (both student-generated and teacher-generated). The results indicated that the two groups that used analogies performed better on the multiple-choice tests and the second question of the open-ended test. The second question on the open-ended test specifically addressed the analogies used during instruction. A multiple regression analysis also revealed a difference between the groups; however, the student performance in the analogy groups was dependent on the amount of prior knowledge in science that they brought to the task. The increase in student performance with analogy instruction could be explained by a number or factors, specifically, conceptual reorganization or creation of new schemata, powerful visualization provided by analogies and high student interest in analogy use.

Creation of New Schema. Conceptual reorganization is theoretically explained by Rumelhart and Norman (1981). Schemata in this perspective are packages of knowledge based on specialized procedures that are employed in the interpretation of events in our environment. They distinguish two types of learning. The first type of learning involves the encoding of new information in terms of existing schemata. No new schemata are developed in this kind of learning. The second type of learning occurs when existing schema are restructured or new schema are created. The results of this research study indicate that new schemata are generated by analogy use. These new schema are generated by transferring structures from the analog (analogy) to the target domain. This type of learning shares many features with Piaget's accomodation process. This research indicates that analogy use allows for the organization or reorganization of knowledge. It does not appear that analogical reasoning ability is developing. It seems as though the richer and more tightly structured one's representation of a system, the easier it becomes to see the structured similarity between it and other systems of knowledge. It is the development of the knowledge base that make it possible to access more and more remote analogs (Vosinadou, 1989). This restructuring of existing schemata and creation of new schemata is one of the premises of constructivism.

The "constructivistic view" (von Glaserfeld, 1983) has become the leading theoretical perspective of science education research on learning processes in the past ten years. The schema theory coincides with the main aspects of the constructivist view. The following two basic ideas of this view are of central importance: (1) learning is an active construction process; and (2) learning is possible only on the basis of previously acquired knowledge. Learning; therefore, has to do with constructing similarities between the new and already known. It is precisely this aspect that emphasizes the significance of analogies in a constructivistic learning approach. Learning is to be viewed mainly as conceptual growth, as a continuous chain of enlargements. Analogies are of pivotal importance in conceptual change learning in that they may help to restructure existing memory and to prepare it for new information (Gentner, 1983). In this perspective, employing an analogy does not merely help or facilitate learning in a new domain, it also opens up new perspectives for viewing and restructuring the analog. In addition, analogies create a powerful visual image that enhances the student's understanding of the concept.

Visualization. The visualization that occurred during analogy use helps explain the success of analogies as an instructional method. The student's level of understanding as measured by the visualization that took place during instruction seems to be dependent on the type of instructional method that they received. When the students were asked a question that demanded an isolated fact of information, the visualization process that took place was very different between the groups. The analogy groups visualized the analogy from their respective groups (i.e., the students visualized their own analogy and the other students visualized the teacher's analogy).The analogy groups demonstrated a better understanding of the concept or "big idea" of protein synthesis, whereas the control group had only a partial understanding of the concept of protein synthesis. The control group visualized fragments of an instructional drawing used for review. It seems that the brighter students were able to integrate facts into a coherent system that included processing the information.

The prevalence and strength of the visual imaging suggest right hemispheric involvement. According to Watzlawick (1978), metaphor and analogy are the language of the right cerebral hemisphere. Most learning involves more traditional learning strategies that involve the left hemisphere. Analogies and emotional investment access the right hemisphere. A more holistic approach to learning that involves both hemispheres seems to achieve better results. The results of this study seem to indicate a strong right hemispheric involvement in the fact that all of the students, regardless of ability or treatment group, initially accessed a visual image in response to an auditory prompt.

High Student Interest. Coupled with the conceptual reorganization of schemata, and a powerful visualization process, high student interest could also explain the success of the instructional use of analogies. All of the students preferred to use analogies over traditional methods of instruction. Students preferred using analogies for a variety of reasons. The students stated that analogies were a more fun and interesting way to learn. The students believed that being able to create their own analogy made the learning more meaningful to them; this is consistent with the constructivst view of learning. The students were cognizant of the fact that sometimes they didn't understand the teacher's analogies because the teacher doesn't always have the same experiences as the students. Incidentally, females preferred using the teacher-generated analogy because they felt that the teacher had more knowledge; therefore, the analogy would be correct. High student interest in analogies coupled with the novelty of a new instructional approach may have contributed to the better performance on the posttests by the student-generated analogy group.

Research Question 2a

What is the nature of the change? How are student-generated and teacher-generated analogies related to the student's subject matter knowledge?

Prior Knowledge. The results of this study indicate that prior knowledge was an important factor in the successful use of analogies. Multiple regression analyses were performed to examine the relationship between prior knowledge and posttest results.In both the immediate posttest and the one-month posttest, prior knowledge was a significant variable in predicting the student's performance on the posttests. In general, it seems as though the students who bring more general science background knowledge with them to science class benefit most from the instructional analogy approach.

This finding is also consistent with Alexander & Judy (1990) in that sixth graders who were low in knowledge of human biology benefitted little from explicit instruction in the general strategy of analogical reasoning. They concluded that without basic competence in the content area, the training of this strategy was not feasible.

The findings in this research regarding the importance of prior knowledge indicate that a foundation of science knowledge seems requisite to the efficient and effective use of analogies. Alexander & Judy (1988), Newell (1980) and Resnick (1987) claim that a certain amount of knowledge in the domain under study is necessary for the efficient use of strategic knowledge. Before a learner can apply strategic knowledge to a content task in a manner that will facilitate completion, the learner must possess some knowledge relevant to that domain. In their examination of experts' and novices' problem solving in genetics, Smith and Good (1984) also concluded that the availability of relevant and appropriate content distinguished successful from unsuccessful problem solvers.

The students who bring more science background knowledge with them perform better using analogies. This could be explained by the fact that these students were bringing more knowledge to the task, therefore, having a better initial understanding of protein synthesis, and then freeing up resources for other tasks such as using analogies. Another explanation for the role of prior knowledge in analogy use may be that the students who have more prior knowledge find analogy use intellectually stimulating and may be more interested in the approach. These same students may have already been using analogies spontaneously and weren't cognizant of the fact that this was how they were learning.

Research Question 2b

How do the subprocesses of analogical reasoning in expert and novice science students compare?

Spontaneous analogical learning can be divided into subprocess of (a) accessing the base system; (b) performing the mapping between the base and target; (c) evaluating the match; (d) storing inferences in the target; and sometimes, (e) extracting the commonalities (Gentner, 1989). This breakdown suggests that the subprocesses be examined independently. This research examined the first two subprocesses in an initial study of analogy use, access and mapping. Although the chronological first step in an experiential learning sequence is accessing the potential analog, mapping processes will be discussed first because it is this process that defines the analogy and allows one to delineate the different kinds of similarities. The method that a subject uses to map their analogy determines what is initially accessed.

Mapping. The central idea in mapping an analogy is that a mapping of knowledge occurs from one content area (the base) into another content area (the target) that conveys a system of relationships that is similar between the two content areas (Gentner, 1989). It is the method that the subject uses to connect the base to the target domain. This method consists of using either descriptors/nouns, adjectives,verbs or all three to describe the similarity between the unknown content and the known content area. Distinguishing these different kinds of similarity is essential to understanding learning by analogy and similarity.

The students' analogies were categorized according to the type of similarity that they created and the words or descriptors that the student used to create their analogy (Genter, 1990). The type of similarity between the student's conceptualization and protein synthesis produced was classified as: an anomaly, mere appearance, literal similarity or an analogy. These types of similarities were based on the number of attributes (nouns, adjectives) and the number of relationships (transitive verbs,comparative adjectives and prepositions) used to characterize the analogy.

A student's analogy was considered an anomaly if it contained few attributes or relationships. A mere appearance contained mainly adjectives to describe the relationship between protein synthesis and the student's analogy. A literal similarity contained some descriptive adjectives and some verbs to describe the relationship between the two topics and an analogy contained mainly verbs to describe the relationship. Mere appearance matches are in a sense the opposite of analogies.These matches are limited in their usefulness because little beyond physical appearance is shared between the two content areas. This data suggest levels of analogical thinking, perhaps, a superficial level and a deeper level of analogical reasoning.

Topic Selection. Before the students could use language to associate the similarities between two content areas, the student needed to first select a topic or a content area that s/he was already familar with. Interviews and questionnaire data indicate that the students selected their topic based on the type of similarity that they perceived their topic to have in common with protein synthesis. The research findings suggest that mapping was strongly influenced by structural similarity and "systematicity". Systematicity refers to mapping an entire system from one content area as opposed to mapping fragments of knowledge from a variety of content areas. There was a significant difference between the students considered to be of a lower ability in science and students of a higher ability in their topic selection and their mapping patterns of similarity. Low ability science students had more tendencies to create their analogies that involved ideas from several systems.

The interview and questionnaire data indicated that eighty-percent of the students selected a topic in a nonscience area. Regardless of ability, the students selected novel and familar topics such as shopping, basketball, soccer, factories, city structure, and various other business structures. The other twenty-percent of the students that selected a topic within a science content area were the high ability science students. They selected topics such as computer programming, the dynamics of hearing and the construction of buildings.

The selection of science content areas by the high ability students is consistent with the multiple-regression findings, in that prior background knowledge in science was beneficial for using analogies. It is clear that many students do not feel that they have a full command of science topics to select it as a possible domain for their analogy.

Other differences surfaced between the two ability groups in their explanation for their topic choices. The majority of the high ability students indicated that they selected their topic because it contained a similar function or relationship as the stages of protein synthesis, while the low ability group stated that they selected their topics because certain items "looked-like" protein synthesis. The low ability students used more nouns or surface features to describe the similarity between their analogy and protein synthesis. The results from the interviews and questionnaires indicated that the high ability students spent more time analyzing a topic for similarities before deciding to create their analogy. In addition, this group of students mapped the components of protein synthesis according to similar functions or structural relationships (verbs).

It seems that the degree of prior background knowledge in science not only predicts how the student will perform on the posttest, but also is important in selecting a topic to create an analogy and in the mapping of the analogy to existing schema or creating new schema. Gentner (1989) claims that mapping relationships or verbs has more inferential power in learning. These differences in topic selection resulted in different types of similarities created by the students.

Type of Similarity. Once the students selected their topics, they had to assign words or descriptors to explain how and why the parts of their analogy were related to protein synthesis. The student's analogies were categorized according to the type of similarity that they created by the language that they used to describe the similarity. The student analogies were classified as: anomaly, mere appearance, literal similarity or an analogy.

Literal similarities (used a combination of verbs and nouns) and analogies were the most frequent types of similarity created by the students. The high ability science students created more analogies and the low ability science students created more literal similarities. This is consistent with the findings from the topic selections and the reasoning the students provided for their choices. However, it is interesting that many low ability science students created analogies. The fact that they were creating 'true analogies' is because they were allowed to work in a familar content area. Allowing the students to select their topics, assuming they selected it because of familiarity, allowed the students to be an "expert" in their domain. These findings were consistent with the findings on expertise and alternative conceptions in science.

Experts excel in a specific domain or content area. There is little evidence that a person highly skilled in one domain can transfer the skill to another (Minsky and Papert, 1974). A very intelligent person might be that way because of specific features of his knowledge-organizing structure rather than because of his global qualities of thinking. The organization of knowledge specific to the domain seems to be important in distinguishing experts from novices. Allowing the student to select his topic for his analogy allows the student to use analogies to organize his/her new knowledge in a more expert-like manner. It seems that analogies allow the student to create new schema or reorganize existing schema into a more meaningful pattern. It seems that by allowing the student to work within a familar topic, energy that the students would normally spend on trying to understand the teacher's analogy or instruction could now be used more effectively. Experts' short-term memory isn't larger than novices, but because of the automaticity of many portions of their skills frees up resources for greater storage of knowledge.

The fact that the student's task involved a goal in creating their analogy also made it more meaningful. Their task was using analogies as a means to an end as opposed to using an analogy as an end. Most of the dated research conducted on theuse of analogies as an instructional tool has been conducted using analogies as an end. Using analogies as an end (i.e., A:B::C:D) in verbal problems out of context didn't show any promise in training students to use analogies spontaneously. However, the method in which analogies were constructed in this study allow for the student to successfully and meaningfully use analogies that promote the spontaneous use of analogies.

Although the study wasn't designed to reveal gender issues, it was interesting to note that the female students preferred teacher-generated analogies rather than student-generated analogies. The females' explanation for their preference was that they felt their analogies weren't always correct and that they trusted the teacher's analogy over their own. On the other hand, the male students preferred creating their own analogies. This could reflect a lack of confidence or science content knowledge which maybe explains why the female students felt more comfortable with the teacher-generated analogy.

The method by which the students linked their analogy and the new information about protein synthesis into new schema or reorganization of existing schema is dependant on the similarity or mapping patterns that the student used. In addition, it's those patterns of similarity that determine what is accessed when a student has to recall information about protein synthesis.

Access. The first subprocess necessary for spontaneous learning by analogy is the issue of access to the analogy and similarity. What governs spontaneous access to similar or analogous situations is dependant on the surface features that the student used to reorganize their schema. This finding is also consistent with Gentner(1987) in that surface features lead to access; therefore, literal similarities and mere-appearance matches are more accessible than true analogies and anomalies. Overall similarity, especially surface similarity, appears to be a major factor in accessing material in long-term memory. Interview and questionnaire data suggest that the surface similarity is in the form of a visual image.

Interviews with students from both the teacher-generated group and the student-generated group reveal a powerful visual imaging process that was involved in accessing information about protein synthesis. Students were asked to recall specific facts about protein synthesis and the concept of protein synthesis. A visual image was initially created for students in both groups; however, there were different visual images between the groups and within the groups. Students who generated their own analogies created an image of their analogy. Students who received the teacher's analogy for instruction created a visual image of the teacher's analogy in most instances. In other instances, the students who didn't understand the analogy created a visual image of the instructional drawing used to review cell physiology. The students who were unable to create the "big picture" or a "system" were later unable to demonstrate a complete understanding of protein synthesis. It seems that the visual images reflected a level of understanding.

Other differences existed between the ability level of the learner. Students with high ability in science had created a more efficient visual imaging technique. These students were able to immediately visualize the specific cell organelle in question. The students with lower science ability had scanned the entire visual image "looking" for the answer to the question. Once these students isolated the answer, the analog was attached to the image (i.e, asked about the function of the mitochondria, they first found the "zigzag" drawing, then "powerhouse" analog). Attached to the analog, "powerhouse", was the scientific word, “mitochondria”. The high ability students were able to recall the scientific understanding of the analog; whereas, the low ability students were generally unable to recall that information.

It would seem likely that the type of visual image accessed was dependent on the type of similarity mapped. The high ability science students generally used relationships or verbs to map or create new schema. These same students were able zero-in specifically for what they were looking for. This finding is consistent with Gentner (1989) that structural relationships have more inferential power in learning.

Summary

There is considerable evidence that students in science courses experience significant conceptual difficulties. Patterns in the errors indicate that the errors are not random and they suggest that students are not simply failing to learn new material, but have alternative conceptions about it. Pretests and interviews given prior to the course show some of the same error patterns and indicate that students are entering courses with alternative conceptions. Similar data taken after courses indicate that some of these preconceptions do not change much and constitute persistent barriers to achieving conceptual understanding. This indicates that courses need to place increased emphasis on dealing with alternative conceptions.

It is clear that some alternative preconceptions are more deep-seated than others. By changing an alternative conception or conceptual change, it means that it could modify the domain of, displace, modify and improve, replace, or suppress a conception, depending on what is most appropriate.

The method used in this study for helping students dealt with persistent alternative conceptions attempted to have students build up their understanding at an intuitive level as well encourage students to become aware of their own alternative conceptions. The use of student-generated analogies means that the scientific concepts to be taught should be grounded on the student's understanding of prior knowledge and alternative conceptions. In order for difficult conceptual material to make sense to the student, it is important to connect somehow with the student's existing knowledge; but the student's existing intuition in the area sometimes is in conflict with the theory being taught. A way around this paradox would be to have the student generate analogies in a familiar domain that would presumably have less cognitive flaws.

Student-generated analogies seem to do a better job at this than traditional textbook instructional methods. Student-generated analogies are similar to applying an expert learning strategy in the classroom. This approach, which relies on a mixture of problem solving, small group discussion and large-group discussion could be viewed as a form of guided constructivism. This type of learning, using student-generated analogies could be viewed as an interaction vs. reception. This method lies midway between pure didactic and pure discovery techniques. The construction of student-generated analogies are more structured than an open discovery technique.

Generally, science knowledge is more abstract and difficult to understand. Using student-generated analogies seem to be a fun way of assessing a level of understanding for both the student and the teacher, and seems to be more effective because processing with analogy takes more memory and a more effortful encoding to retain the information.

Creating analogies allows the student to become actively engaged in evaluating whether their examples are analogous or not and finding the best way to view the target situation. In this way the method departs from purely didactic methods and from a model of teaching where knowledge is "piped directly into the empty vessel" of the student. It does so by drawing out prior knowledge in the student and interacting with it in a number of ways rather than simply transferring knowledge. These interactions take the form of conflicts between the students alternative conceptions and the accepted scientific theory. Thus the lessons emphasize interaction with the prior knowledge and reasoning abilities of the students as a form of guided constructivism. This form of guided constructivism, or student-generated analogies seems to most effective under certain conditions.

In constructing a possible instructional recipe for imparting scientific concepts one needs to consider the conditions under which students undergo a conceptual change with student-generated analogies. It seems as though six conditions need to be present in order for students to undergo a conceptual change: 1) Students must be trained when to use analogies; 2) Students must possess some minimum understanding of the scientific concepts; 3) Students must map a "system" when they create their analogies; 4) The goal of the analogy must be a means to an end; 5) The analogy should include a visualization; and 6) Teacher/student rapport is necessary so that the students are comfortable discussing their alternativeconceptionsin a nonjudgmental environment.

Although there is no single, optimal instructional approach for bringing about conceptual change there are also some essential ingredients that are controlled by teachers. First, instruction needs to have its focus probing for, and listening to, students' beliefs, rather than merely transmitting knowledge. Only by probing for understanding will teachers be able to determine when students possess misconceptions that are in conflict with the scientific concepts targeted for instruction. In addition, teachers need to possess considerable knowledge of science content in order to be able to determine whether the conceptions held by students are misconceptions. Further, when a misconception or alternative conception is identified, a teacher needs to be able to induce dissatisfaction in students in order to initiate the process of conceptual change. Finally, the teacher needs to guide students in reconstruing their knowledge, this is similar to the "bridging analogies technique".

The constructivist view takes cognizance of the fact that students' conceptual knowledge evolves in time and many misconceptions will disappear naturally as students gain expertise. The use of self-generated analogies requires a willingness and ability to conjecture, to see the value of one's own ideas, and to view scientific explanations as tentative and open to evaluation and change. Many social and cultural characteristics of middle school students and middle school science classes militate against the assumptions underlying the relationship between self-generated analogies and conceptual growth.

Traditional methods of teaching science were not as effective as instruction with analogies. Instructional use of analogies clearly produced students with more knowledge about protein synthesis. However, it is unclear whether teacher-generated analogies or student-generated analogies were more effective. Instruction with analogies was superior because of the conceptual reorganization that analogies provoke, the visualization that occurs during analogy use and student interest in the novel method of teaching. An interesting caveat to the importance of the instructional method, was the importance of prior background knowledge in science.

Prior science background knowledge coupled with the instructional method of analogies was predicted to be more effective in increasing the student's understanding of protein synthesis. The student's prior knoweldge seemed to determine the topic selected for the creation of the analogy, how the analogy was mapped and later, how the analogy was accessed. Differences existed between the two ability groups, which is also consistent with the findings on the significance of prior knowledge.

Implications for Further Research

The analysis of data raises some interesting questions for future research about the nature of analogies in the science classroom. It would be interesting to increase the length of intervention to determine whether or not students could be trained to use analogies spontaneously. If students could be trained to use them spontaneously, this method of instruction could have powerful implications for increasing the competency of American science students.

Differences between the teacher-generated and student-generated analogy groups need to be explored in more detail. It was unclear whether one strategy was more effective than the other. This finding would have powerful implications for today's educational reform. Training students to create analogies using verbs to create the similarities in their analogies would create analogies with more inferential power.

Another factor explaining the better performance of the student-generated group could be the fact that the student-generated group was able to "think aloud" during the construction of their analogies. These students worked in groups of two to three "brainstorming" their ideas with one another. Much of the research on verbalization has confirmed that some kind of thinking aloud is beneficial both during practice/learning trials and on transfer of learning to other tasks (Chi, 1983). When the students are required to "stop and think", verbalization "slows them down" (Berry and Broadbent, 1987). Berry and Broadbent (1987) also propose that "temporary cognitive units" must be activated at the time they are needed, if lasting domain knowledge is to be enhanced. These participants in the above studies were also asked to explain oneself in making a particular solution attempt or trial.

A shift in attention from focusing on aspects of the problem itself to a focus on what one is doing to solve the problem is metacognitive processing. This metacognitive processing that involves self-monitoring, self-evaluating, and self-regulating of ongoing tasks was more evident in the student-generated group. The student-generated group was the only group that had an opportunity to engage in any kind of reflective thinking. This metacognitive processing, which was invoked in response to the creation of the analogies, might be responsible for the improved performance of the student-generated group. This is consistent with Ericcson and Simon's (1984) extensive investigation into the effects of verbalization on problem-solving. They suggest that simple think-aloud-type verbalizations will not interfere with or change performance, because participants are simply stating what is currently in their working memory. Ericcson and Simon also state that asking for explanations requires participants to bring into short-term memory that which is not normally stored there.The student-generated group was required to shift processing levels (from the problem level of generating an analogy to the metacognitive level) that enabled the student to acquire the relevant problem knowledge and understand its application.The forced metacognitive processing coupled with working with already existing schema (from a familar domain) allows the student to encode the information in a more meaningful way.

The idea of alternative conceptions needs to be explored. One of the limitations of analogy use is that they can create misconceptions. However, the student-generated approach would help alleviate this problem by having the students examine the limitations of their analogies themselves. This would stimulate the development of their critical thinking skills. Students could be encouraged to learn by contrasting dissimilar situations as well as be seeing similarities.

The powerful visualization that was taking place during analogy use also needs to be explored in further detail. It would be interesting to investigate the effects of analogy without providing a visual image. The relative strength of the visualization versus the actual analogy itself would be interesting in terms of a more holistic approach to teaching science. It would also be interesting to explore the visualization supplemented with auditory training, for instance, if the students were told to imagine the sound of the wheels turning as they visualized the car moving.

In any case, analogy use is a powerful tool and much more research needs to be conducted in the field. To use an analogy, gaining access to long-term memory is a bit like fishing with a nightcrawler in the Mississippi River: The learner can bait thehook-that is, set up the working memory-as he or she chooses, but once the line is thrown into the water it is impossible to predict exactly which fish will bite.

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APPENDIXES

Appendix A

Informed Consent Form

I am Mrs. Pittman, a doctoral student at National-Louis University in Evanston. One of the requirements for my degree is the completion of a research dissertation. My area of interest is pursuing effective teaching strategies in science education for junior high students.This research will require using the student's class test scores in science and some of their scores from the California Test of Basic Skills. In addition, some of the students' explanations may be audiotaped and/or videotaped during the study. The scores will be confidential and will not be reflected in their course grade.The student is not obligated to participate in the study and may withdraw at any time. A summary of my findings will be available at the conclusion of the study.

I give my permission for the use of test scores and also, if necessary will allow my audiotape or videotape results to be used in the study. I understand that I may withdraw from the study at any time.

student signature	student name (printed)
parent signature	date

As always, if you have any questions, please feel free to contact me at 998-5020 between 2:30 and 3:00. Thank you.

Appendix B

Protein Synthesis Pretest

Circle the letter of the answer that best completes each statement.

1. A DNA molecule looks like a (an)
   a. large ball b. eight-sided crystal c. long, thin thread d. twisted ladder.

2. Which of the following is not a base in a DNA molecule?
   a. adenine b. uracil c. cytosine d. guanine

3.The process by which DNA molecules form exact duplicates is called
   a. replication b. transcription c. translation d. protein synthesis

4. The production of proteins is called
   a. replication b. transcription c. translation d. protein synthesis

5. Proteins are made up of chains of small molecules called
   a. DNA b. RNA c. amino acids d. phosphates

6. Proteins
   a. are necessary for building & repairing body cells b. control vital body functions c. make up digestive enzymes d. all of the above

7. If one strand of DNA has the bases AACTG, the other strand has bases
   a. TTGAC b. AACTG c. UUGAC d. AACUC

8. The substance that carries the genetic code of DNA from the nucleus to the cytoplasm is
   a. thymine b. deoxyribonucleic acid c. RNA d. a gene

9. Which substance is not found in an RNA molecule?
   a. adenine b. cytosine c. guanine d. thymine

10. Which of the following is a correct pairing of bases in a DNA molecule?
    a. cytosine-adenine b. cytosine-thymine c. cytosine-cytosine d. cytosine-guanine

11. DNA is a
    a. carbohydrate b. lipid c. nucleic acid d. sterol

12. If the code for an amino acid is ATG on the DNA molecule, this code on the transfer RNA molecule may be written as
    a. ATG b. CTG c. AUG d. CTA

13. Between which types of compounds in a double-stranded DNA molecule must the bonds break before replication takes place?
    a. phosphate-base b. sugar-phosphate c. adenine-thymine d. sugar-base

14. To which organelles is messenger RNA attached
    a. chloroplasts b. ribosomes c. mitochondria d. lysosomes

15. Transfer RNA is found in the
    a. mitochondria b. cytoplasm c. endoplasmic reticulum d. lysosomes

16. Unlike DNA, RNA
    a. contains deoxyribose b. is double stranded c. contains thymine d. contains uracil

17. Each combination of three nitrogenous bases on messenger RNA forms a (an)
    a. anticodon b. codon c. enzyme d. nucleic acid

18. If one strand of DNA contains the nitrogenous bases AACTG, its complementary strand contains the bases
    a. AACVG b. UUGAC c. TTGAC d. AACTG

19. The following are steps in protein synthesis. Which is the first step that is out of order?
    a. mRNA bonds to two subunits of a ribosome
    b. amino acids bond to form a polypeptide chain
    c. the initiator codon binds the first anticodon of transfer RNA
    d. the anticodon of another transfer RNA binds to mRNA

20. The synthesis of a new double strand of DNA begins when the two strands of the original DNA helix
    a. "unzip" b. act as a template c. attract nitrogenous bases d. destroy a genetic code

Appendix C

Alternative Conceptions

Answer all questions completely. You may describe your answers by describing it in writing or using illustrations.

1. What is a protein? Why are they important?

2. How are proteins made in the body?

Appendix D

Protein Synthesis Lecture

The DNA molecule:

DNA stands for deoxyribonucleic acid. The DNA molecule is the basic substance of heredity. DNA stores and passes on genetic information from one generation to the next.

The Structure of DNA (a review):

A DNA molecule looks like a twisted ladder, or spiral staircase. The sides of the ladder are made up of sugar molecules and phosphate groups. The steps, or rungs, of the ladder are formed by pairs of substances called nitrogen bases. There are 4 different nitrogen bases in DNA, they are adenine, guanine, cytosine, and thymine. The capital letters A,G,C, and T are used to represent them. Adenine always pairs with Thymine, and Cytosine always pairs with Guanine.

Cell Reproduction:

As an organism grows and develops, the number of body cells must increase. In order for the total number of cells to increase and for the organism to grow, each cell must reproduce. For a parent cell to reproduce two identical cells, the exact contents of its nucleus must be transferred into the nucleus of each new cell.

DNA Replication:

The process in which DNA molecules form exact duplicates is called replication. The first step involves the unzipping of the DNA molecule. As the DNA ladder splits into 2 halves, free nitrogen bases that are floating in the nucleus begin to pair up with the nitrogen bases on each strand of the DNA ladder. A+T and C+G.

Protein Synthesis:

Chromosomes are made up of long strands of DNA molecules. The chromosome controls the production of proteins. Functions of proteins: building and repairing cells, hormones, control body functions, makes enzymes.

The production of proteins is called protein synthesis. Proteins are long molecules that are made up of chains of smaller molecules called amino acids.There are 20 different amino acids that join together to form protein molecules. It is the job of the DNA molecules in chromosomes to control the order in which these 20 amino acids are put together to make a protein molecule. How does DNA do this?

Translating the Genetic Code

How does an RNA molecule translate the genetic code of a DNA molecule?

1. As in replication, a molecule of **DNA** first unzips between nitrogen base pairs.

2. Then each strand of the DNA molecule directs the production of a complementary strand of **mRNA**.This is transcription. Transcription is the process by which a molecule of DNA is copied into a complementary strand of RNA, the process of transferring information from DNA to RNA. C joins with G, A joins with **U**racil instead of thymine. (The DNA strand is transferred to the mRNA strand).

3.The mRNA (messenger RNA) molecule then carries the genetic information out of the nucleus through the **endoplasmic reticulum** to the **ribosome,**where proteins are made.

4.The genetic information that DNA transfers to mRNA (messenger RNA) is in the form of a code made of three-letter code words. The decoding of a messenger RNA message into a protein is known as translation. Each code word consists of three nitrogen bases- for example, AUG or ACA. The triplet on mRNA is called the **CODON.** There are 64 possible 3-letter code words. Each 3-letter code word specifies a particular **amino acid** to be added to the growing protein chain. Other code words function as "start" and "stop" (AUG means "start"; UAA, UAG, and UGA mean "stop").

5. The mRNA molecule that carries the coded message for a specific protein does not actually produce the protein itself. Putting together the amino acids in a protein chain is the next step in protein synthesis, and it requires another form of RNA. This is **transfer RNA (tRNA)**. A tRNA molecule reads the code and begins putting together amino acids to made a protein chain. The tRNA brings the complementary pair **(ANTICODON)** to the codon to make the amino acid. As each anticodon and codon bind together, a peptide **(hydrogen)** bond forms between the two amino acids. tRNA is a single strand of RNA that loops back on itself. Each tRNA molecule has two important sites of attachment. One site, called the anticodon, binds to the codon on the mRNA. The other site attaches to a particular amino acid. During protein synthesis, the anticodon of a rRNA molecule base pairs with the appropriate mRNA codon. When a "stop" code is reached, a complete protein molecule has been produced, and protein synthesis is complete.

Appendix E

Protein Synthesis Lab Activity

Protein Synthesis

Protein synthesis is a complex process. In this activity you will trace the steps that are involved in the protein synthesis of a part of a molecule of oxytocin. Oxytocin is the pituitary hormone that helps regulate blood pressure, stimulates the uterus to contract during childbirth, and stimulates the production of milk after childbirth.

A. Protein synthesis begins with DNA in the nucleus. Below is a DNA sequence that could code for part of a molecule of oxytocin. Write the sequence of messenger RNA (mRNA) codons that would result from the transcription of this portion of DNA. The arrow marks the starting point.

↓ ACA	ATA	TAG	CTT	TTG	ACG	GGG	AAC	CCC	ATT
1	2	3	4	5	6	7	8	9	10

mRNA:
↓

B. After transcription, mRNA attaches to a ribosome, where translation takes place. Each codon of mRNA bonds with an anticodon of a transfer RNA (tRNA) and each tRNA molecule bonds with a specific amino acid. The table below shows the mRNA codons and the amino acids for which they code. For example, if you were given the codon AGA, you can see from the table that these bases code for the amino acid arginine.

	Second Base in Code				
First Base in Code	A	G	U	C	Third Base in Code
A	Lysine Lysine Asparagine Asparagine	Arginine Arginine Serine Serine	Isoleucine Methionine Isoleucine Isoleucine	Threonine Threonine Threonine Threonine	A G U C
G	Glutamic acid Glutamic acid Aspartic acid Aspartic acid	Glycine Glycine Glycine Glycine	Valine Valine Valine Valine	Alanine Alanine Alanine Alanine	A G U C
U	STOP STOP Tyrosine Tyrosine	STOP Trytophan Cysteine Cysteine	Leucine Leucine Phenylalanine Phenylalanine	Serine Serine Serine Serine	A G U C
C	Glutamine Glutamine Histidine Histidine	Arginine Arginine Arginine Arginine	Leucine Leucine Leucine Leucine	Proline Proline Proline Proline	A G U C

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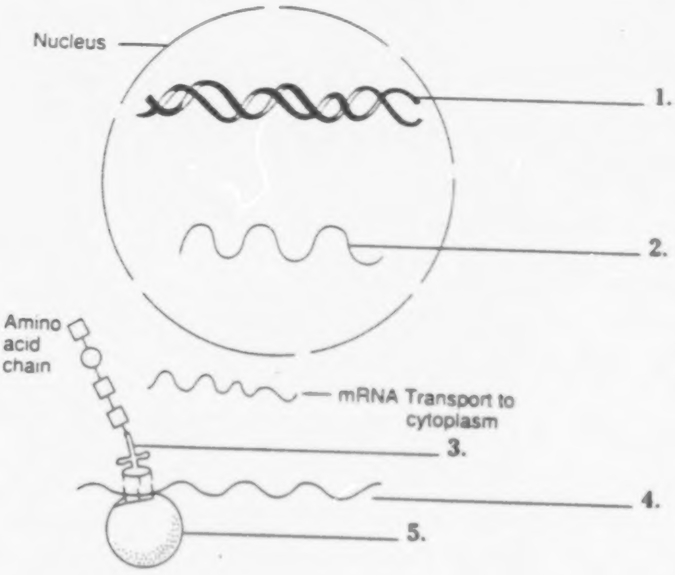
Use your mRNA sequence from **A** to write the sequence of amino acids in this part of the oxytocin molecule.

↓

1. How many amino acids make up this portion of the oxytocin molecule?
2. What is the purpose of the UAA codon?

C. In order to get another view of the entire process of protein synthesis, label the structures on the diagram below.



D. To complete the chart below, give the name and a brief description of each step in protein synthesis that occurs in the part of the cell shown in **C**.

Part of cell	Name of Protein Synthesis Process	Description
Nucleus		
Ribosome		
Cytoplasm		

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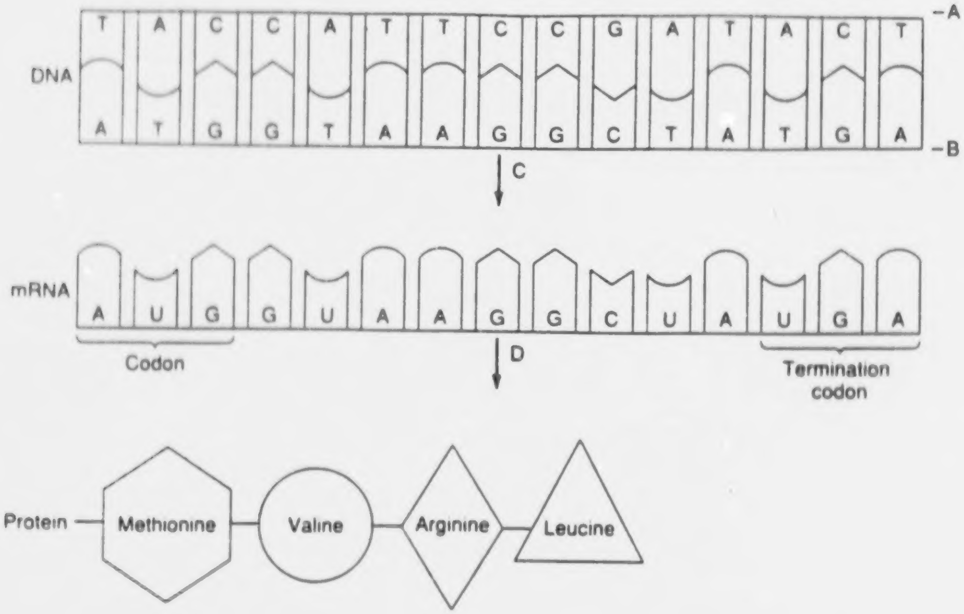
Using Science Skills: Interpreting diagrams


DNA
T A C C A T T C C G A T A C T
A T G G T A A G G C T A T G A
A
B
C
mRNA
A U G G U A A G G C U A U G A
Codon
D
Termination codon
Protein
Methionine
Valine
Arginine
Leucine

The figure above shows the processes that occur in a section of DNA during protein synthesis.

1. Which strand, A or B, is transcribed?
2. What process is represented by D?
3. Which nitrogenous bases in mRNA code for the amino acid valine?
4. Why are only four amino acids produced by five codons?

Essay Discuss each of the following.

1. Compare replication and transcription.

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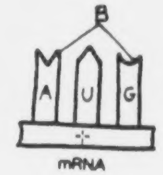
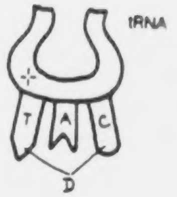
Appendix F

Protein Translation-Homework

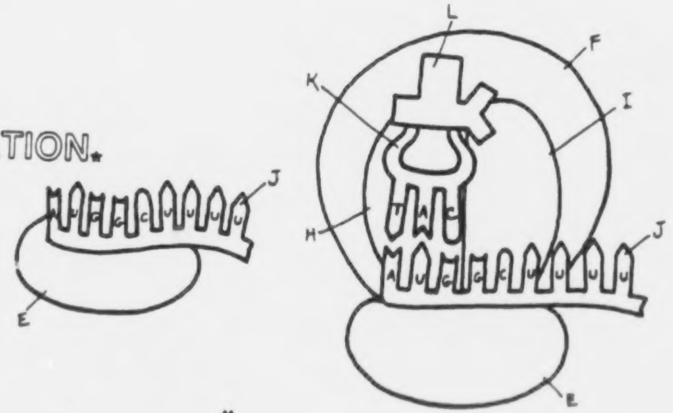
PROTEIN SYNTHESIS: TRANSLATION.

CODON$_B$
ANTICODON$_D$
RIBOSOME*
SMALL SUBUNIT$_E$
LARGE SUBUNIT$_F$
P SITE$_H$
A SITE$_I$

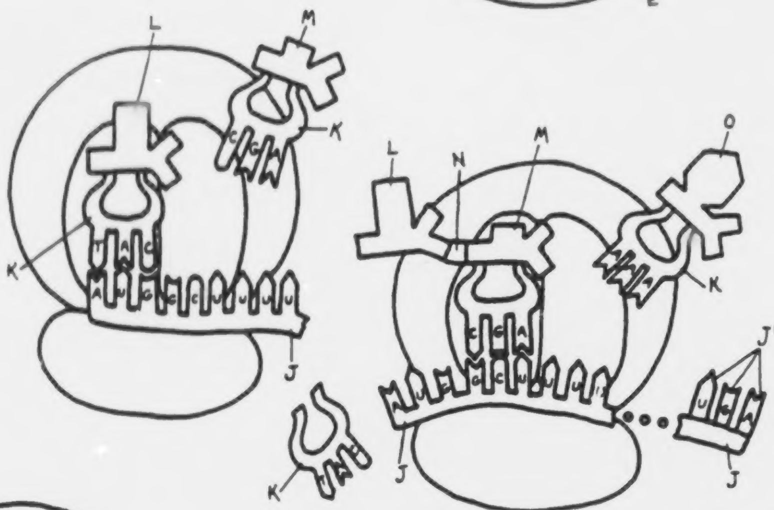




PHASES OF TRANSLATION*
INITIATION*
mRNA$_J$
tRNA$_K$
METHIONINE$_L$



ELONGATION*
ALANINE$_M$
PEPTIDE BOND$_N$
PHENYLALANINE$_O$
STOP CODON$_{J'}$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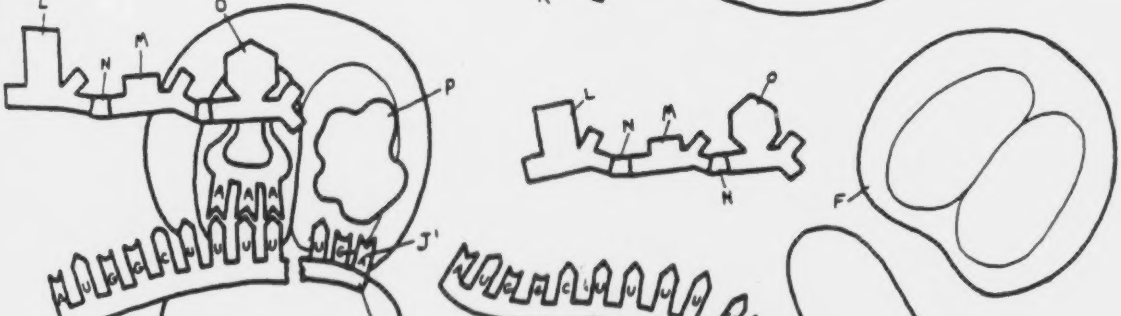
TERMINATION*
RELEASE
FACTOR$_P$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Appendix G

Cracking the Code Activity

Overview: Students decipher "messages" written in triplet code.

Objectives: To familiarize students with the process of translating the three letter code that genetic material uses to code for amino acids

Skills: Sorting and grouping, recognizing patterns

Materials Needed: handout for each student

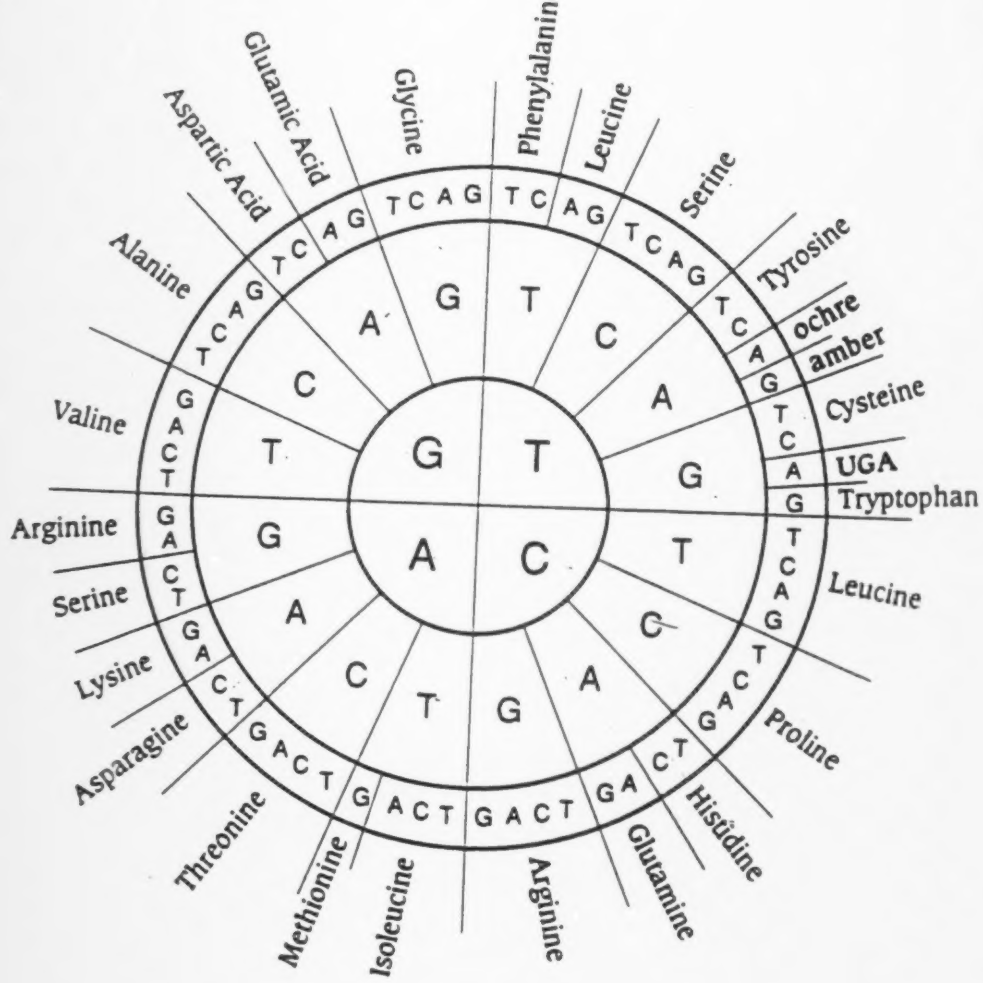
Preparation: None

Lesson Suggestions: There are several ways to go about this; you may want to give each student their own worksheet, or divide the room into several teams and make it a race against time!

Explain the use of the code rings.
To translate a three letter codon, find the first letter in the center of the ring. In that quarter find the second letter in the middle ring, and then the third letter in the outer ring; each triplet codes for only one amino acid, which is listed on the outer edge of the ring.

To complete the translation, look up the amino acid on the table below the ring, and find the one-letter abbreviation. Write that single letter above the three letter codon in the secret message.

Stress that accuracy counts... if anyone transcribes the wrong letters or makes the wrong translation, you can turn it into a lesson about how mutations occur. (Is the word different as a result of the misread code? What would happen if the wrong amino acids were strung together?)


G
T
A
C
Phenylalanine
Leucine
Serine
Tyrosine
ochre
amber
Cysteine
UGA
Tryptophan
Leucine
Proline
Histidine
Glutamine
Arginine
Isoleucine
Methionine
Threonine
Asparagine
Lysine
Serine
Arginine
Valine
Alanine
Aspartic Acid
Glutamic Acid
Glycine

One Letter Codes for Amino Acids:

Alanine	A
Arginine	R
Asparagine	N
Aspartic Acid	D
Cysteine	C
Glutamic Acid	E
Glutamine	Q
Glycine	G
Histidine	H
Isoleucine	I
Leucine	L
Lysine	K
Methionine	M
Phenylalanine	F
Proline	P
Serine	S
Threonine	T
Tryptophan	W
Tyrosine	Y
Valine	V

Molecular Biology-Concepts
Handout
All Ages

Greetings, Agent Triple-X!

Intelligence sources have revealed to us that the terrorist organization CLONE (the Conspiracy to Liberate Obnoxious and Nasty Enemies) is preparing to threaten the free world with a terrible and secret plot.

Our agents have intercepted several messages from CLONE which we believe may contain information about this dreaded plot. Unfortunately, all of the messages are written in the insidious GENETIC CODE.

Your mission, Triple-X, is to translate the codes, using the code key provided. Fill in the correct single-letter abbreviation for the amino acid that is coded by each triplet. Good Luck!

TGT GCT TTA TTG ATT AAC GGA GCC TTA TTG

GAT - AAT - GCG GGG GAG AAT ACG TCT:

TCC AAA ATA CCC TGC TTA GCT TCA TCT,

GAA GTA GCC GAC GAG

ACC GAG GCA TGT CAT GAG AGG TCC,

GCT AAC GAC ATG GAG GAA ACG GCT ACA

CAT GAA GCC GAT CAA U GCT AGG ACT GAG AGG TCG

GCA ACG TTT ATC GTC GAA CCC ATG.

Greetings, Agent Triple-X!

Message to Agent Triple X - continued

TTT ATT AAC GAT ACG CAT GAG

GGG GAA AAT GAG ACT ATC TGT ATG GCA CCC

CAT ATC GAT GAC GAG AAC ATC AAT

ACA CAC GAA GAA TTG ATG ACC AGG GAG GAA

O CCT GAA AGG GCT ACT ATA **O** AAT

"GGC GAA AAC GAG TCA CCA TTG ATT TGT GAA"

ACC GCT AAA GAA TCT CCA TTG GCA TGT GAG

GCG ACC ATG ATT GAC AAT ATA GGA CAC ACT

ATC AAC GGT GAG AAT GAG GTG GCT

Appendix H

STUDENT-GENERATED ANALOGY

An analogy is a relationship between one pair of words or terms that serves as the basis for the creation of another pair of words. If the analogy has been completed correctly, the terms in the second pair have the same relationship to each other as do the terms in the first pair.

Practice the following analogies before you do the exercise. Read the first pair of words and think about the relationship between them.

Happy is to sad as generous is to ________________.
Narrow is to thin as wide is to ____________________.
Forward is to backward as smart is to ________________.
Dull is to sharp as beautiful is to ______________.

NOW, Create your own analogy of protein synthesis. Be sure to include the following terms: **amino acids, proteins, hydrogen bonds, mRNA (messenger RNA), DNA, tRNA (transfer RNA), ribosomes, endoplasmic reticulum, codons and anticodons.**

Draw and label the structures and functions of your analogy. After you create your analogy, you are to apply your analogy to the specifics of protein synthesis on the following page. On the last page, summarzie replication, transcription and translation.

Appendix I

Student-Generated Analogy Worksheet

Apply your analogy to the specifics of protein synthesis:

X Y(Your word) How is X like Y? How is X different from Y?

Anticodon(____________)____

Codon(______________)____

Amino Acids(__________)____

Proteins(______________)______________________________________

Endoplasmic Reticulum(______________)__________________________

Ribosomes(______________)____________________________________

mRNA(________________)______________________________________

tRNA(________________)______________________________________

DNA(________________)____

Hydrogen Bonds (______________)______________________________

Appendix J

Teacher-Generated Analogy for Protein Synthesis

School Scenario:

The principal of the school, Mrs. Smith, would like the teacher Mr. Jones to write a letter to the parents of his students announcing the upcoming Open House. Mrs. Smith asks her secretary, Miss Brown, to take the message to Mr. Jones. Mr. Jones agrees to write the letter, but he lacks certain pieces of information. He sends John to find out the date of the Open House. Susan is to learn about the program for the evening. Eric is asked to get a list of the parents' names and addresses. Once he has all of the necessary information, Mr. Jones writes the letter, and it is sent to all the parents.

School Person(X)	**Cell structure (Y)**	**How is X like Y?**
Principal (Mrs. Smith)	DNA	Control activities of cell & school
Teacher (Mr. Jones)	Ribosome	Makes protein, writes letter
Secretary (Miss Brown)	mRNA	Take the message from the DNA
John	tRNA	Gets necessary information
Susan	Amino Acid	Part of the necessary information
Eric	tRNA	Gets remaining details
Letter	Protein	The completed message/letter
Connected paragraphs of letter	Peptide/Hydrogen Bonds	Connect all amino acids and paragraphs of the letter
Paragraphs	Amino Acids	Parts of the protein/ letter
Letter sent home	Cell membrane	The protein leaves

Note. From *Biology*, Prentice-Hall, 1993, p. 222.

Appendix K
Protein Synthesis Posttest (Form B)

Circle the letter of the answer that best completes each statement.

1. DNA is a
   a. carbohydrate b. lipid c. nucleic acid d. sterol

2. Which of the following is a correct pairing of bases in a DNA molecule?
   a. cytosine-adenine b. cytosine-thymine c. cytosine-cytosine d. cytosine-guanine

3. Which substance is not found in an RNA molecule?
   a. adenine b. cytosine c. guanine d. thymine

4. The substance that carries the genetic code of DNA from the nucleus to the cytoplasm is
   a. thymine b. deoxyribonucleic acid c. RNA d. a gene

5. If one strand of DNA has the bases AACTG, the other strand has bases
   a. TTGAC b. AACTG c. UUGAC d. AACUC

6. Proteins
   a. are necessary for building & repairing body cells b. control vital body functions c. make up digestive enzymes d. all of the above

7. Proteins are made up of chains of small molecules called
   a. DNA b. RNA c. amino acids d. phosphates

8. The production of proteins is called
   a. replication b. transcription c. translation d. protein synthesis

9. The process by which DNA molecules form exact duplicates is called
   a. replication b. transcription c. translation d. protein synthesis

10. Which of the following is not a base in a DNA molecule?
    a. adenine b. uracil c. cytosine d. guanine

11. A DNA molecule looks like a (an)
    a. large ball b. eight-sided crystal c. long, thin thread d. twisted ladder

12. The synthesis of a new double strand of DNA begins when the two strands of the original DNA helix
    a. "unzip" b. act as a template c. attract nitrogenous bases d. destroy a genetic code

13. The following are steps in protein synthesis. Which is the first step that is out of order?
    a. mRNA bonds to two subunits of a ribosome
    b. amino acids bond to form a polypeptide chain
    c. the initiator codon binds the first anticodon of transfer RNA
    d. the anticodon of another transfer RNA binds to mRNA

14. If one strand of DNA contains the nitrogenous bases AACTG, its complementary strand contains the bases
    a. AACUG b. UUGAC c. TTGAC d. AACTG

15. Each combination of three nitrogenous bases on mRNA forms a (an)
    a. anticodon b. codon c. enzyme d. nucleic acid

16. Unlike DNA, RNA
    a. contains deoxyribose b. is double stranded c. contains thymine d. contains uracil

17. Transfer RNA is found in the
    a. mitochondria b. cytoplasm c. endoplasmic reticulum d. lysosomes

18. To which organelles is messenger RNA attached
    a. chloroplasts b. ribosomes c. mitochondria d. lysosomes

19. Between which types of compounds in a double-stranded DNA molecule must the bonds break before replication takes place?
    a. phosphate-base b. sugar-phosphate c. adenine-thymine d. sugar-base

20. If the code for an amino acid is ATG on the DNA molecule, this code on the transfer RNA molecule may be written as
    a. ATG b. CTG c. AUG c. CTA

Appendix L

Protein Synthesis Posttest (Form C)

Circle the letter of the answer that best completes each statement.

1. A twisted ladder resembles the structure of a
   a. mRNA b. tRNA c. DNA d. rRNA

2. Which of the following is not a base in a DNA molecule?
   a. uracil b. guanine c. cytosine d. adenine

3. Small chains of amino acid molecules make up
   a. nucleic acids b. proteins c. carbohydrates d. fats

4. The cytoplasm is the storage area for
   a. tRNA b. mRNA d. rRNA d. DNA

5. If the code for an amino acid is AAA on the DNA molecule, this code on the tRNA molecule may be written as
   a. GGG b. TTT c. UUU d. CCC

6. Ribosomes are the site of attachment for
   a. tRNA b. DNA c. rRNA c. mRNA

7. An example of a nucleic acid is
   a. fat b. DNA c. carbohydrate d. amino acid

8. Which of the following is an incorrect pairing of bases in a DNA molecule?
   a. cytosine-adenine b. adenine-thymine c. guanine-cytosine d. thymine-adenine

9. The substance that carries the genetic code of DNA from the nucleus to the cytoplasm is
   a. thymine b. deoxyribonucleic acid c. RNA d. a gene

10. The molecule responsible for building and repairing body cells is
    a. fats b. proteins c. amino acids d. carbohydrates

11. Unlike RNA, DNA
    a. contains ribonucleic acid b. is doubled stranded c. contains uracil d. is involved in translation

12. If one strand of DNA contains the nitrogenous bases AAGGT, its complementary strand contains the bases
    a. AACCA b. TTCCA c. UUCCA d. TTCCU

13. The following are steps in protein synthesis. Which is the first of the process?
    a. mRNA bonds to two subunits of a ribosome
    b. amino acids bond to form a polypeptide chain
    c. the initiator codon binds the first anticodon of tRNA
    d. the anticodon of another transfer RNA binds to mRNA

14. Each combination of three nitrogenous bases on messenger RNA forms a (an)
    a. anticodon b. codon c. enzyme d. nucleic acid

15. Between which types of compounds in a double-stranded DNA molecule must the bonds break before replication takes place?
    a. phosphate-base b. sugar-phosphate c. adenine-thymine d. sugar-base

16. The synthesis of a new double strand of DNA begins when the two strands of the original DNA helix
    a. "unzip" b. act as a template c. attract nitrogenous bases d. destroy a genetic code

17. Replication takes place in the
    a. cytoplasm b. nucleus c. ribosome d. endoplasmic reticulum

18. Transfer RNA is mainly involved in the process of
    a. replication b. transcription c. translation d. duplication

19. Protein synthesis starts with the
    a. mRNA b. tRNA c. rRNA d. DNA

20. A codon is found on the
    a. tRNA b. mRNA c. DNA d. rRNA

From Miller Biology Textbook, Prentice-Hall, 1994.

Appendix M

Questionnaire

Answer all questions completely.

1. Does protein synthesis remind you of anything familiar to you in everyday life? If so, what?

2. When I ask you to explain protein synthesis what immediately comes to mind?

3. What does a ______________ remind you of?

    protein-
    amino acid-
    tRNA-
    mRNA-
    codon-
    endoplasmic reticulum-
    ribosome-
    anticodon-

4. Why did you select your topic for your analogy?

5. Do you like using analogies? Why or why not?

6. Does protein synthesis create a "picture" in your mind? If so, what?

7. Did the analogy help you to understand protein synthesis better? Why or why not?

8. Do you think student-generated or teacher-generated analogies are more helpful in learning science?

Appendix N

Interview Questions

1. Does protein synthesis remind you of anything familiar to you in your everyday life?

2. What is the function of the mitochondria?

    a. Retrace your thinking. What was the first thing that came to your mind when I said, "mitochondria?"

    b. Tell me as exactly as you can how you got to your answer.

3. What is the first thing that comes to your mind when I say "protein synthesis?"

4. Do you like using analogies? Why or why not?

5. Do you prefer to make your own analogies, or do you prefer that the teacher make the analogies?

6. Do analogies create a picture in your mind? If so, what kind of a picture does protein synthesis create?

7. If I don't give you a picture with the analogy, do you still see a picture?

Appendix O

Analogy Score Sheet

Name ______________________________ Age _________
CSI __________

Treatment Group ____________________ Gender ______
Expert/Novice

Base Domain-Access:

Near (within science) or

Far (outside of science)

Characteristics-Mapped:

Attributes (surface features=adjectives/nouns)

Structural (relationships=transitive verbs (chases,causes); comparative adjectives (is longer than), and prepositions (X is inside of Y)

Both (attributes and structural components)

Type of Similarity Mapped:

Anomaly (few attributes, few relations)

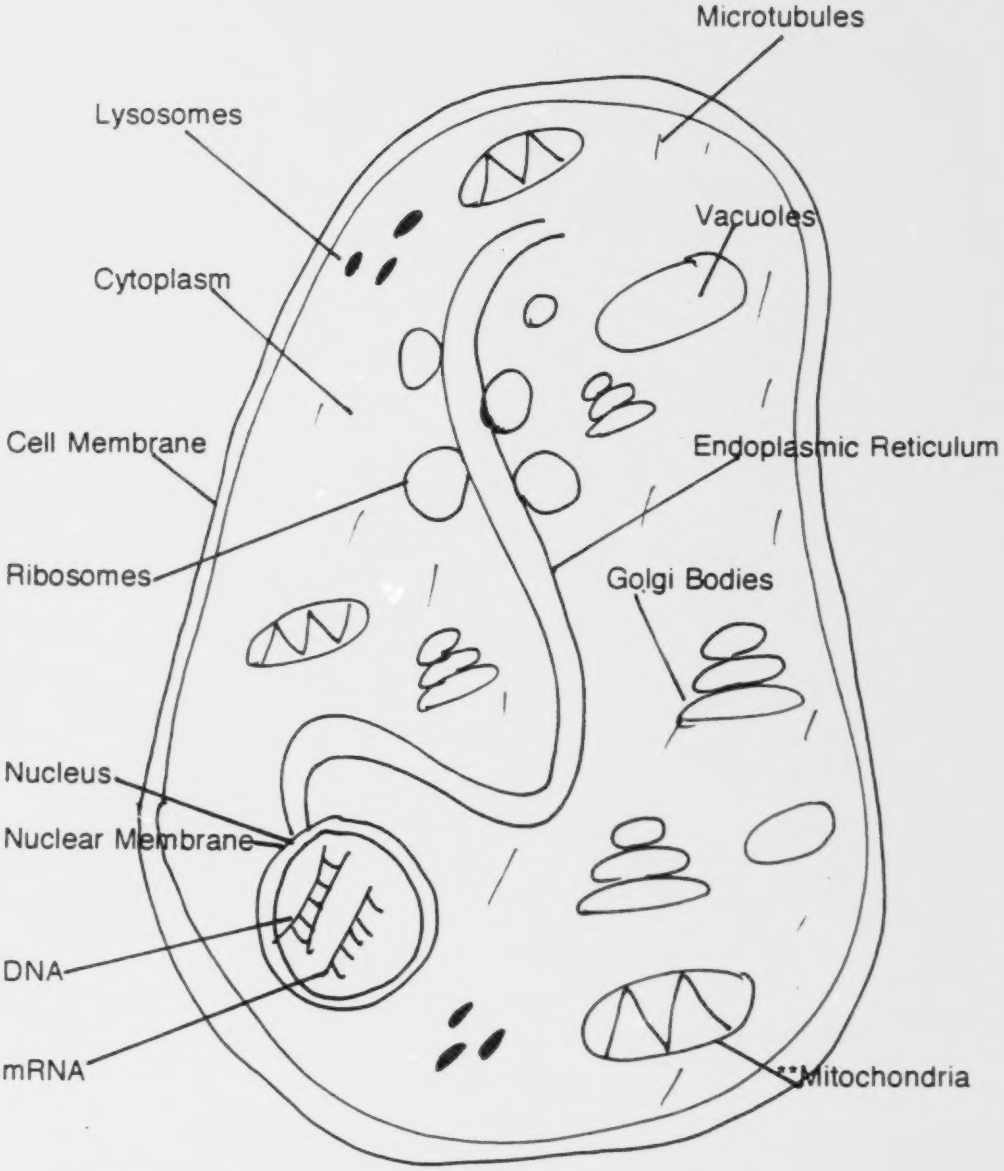
Mere appearance (many attributes, few relations)

Literal similarity (many attributes, many relations)

Analogy (few attributes, many relations)

Appendix P

Instructional Drawing of the Cell


Microtubules
Lysosomes
Vacuoles
Cytoplasm
Cell Membrane
Endoplasmic Reticulum
Ribosomes
Golgi Bodies
Nucleus
Nuclear Membrane
DNA
mRNA
**Mitochondria

The illustration of " protein synthesis" that was provided to the control group, student-generated group and the teacher-generated group to introduce the topic of protein synthesis . The ** mitochondria was the word that the student's were asked to recall by an auditory prompt.

Appendix Q

Student X's Alternative Conceptions Pretest

1. What is a protein? Why are they important?

Protein

Something in food. They go to kidneys & are turned into urea They are important nutrients in them.

2. How are proteins made in the body?

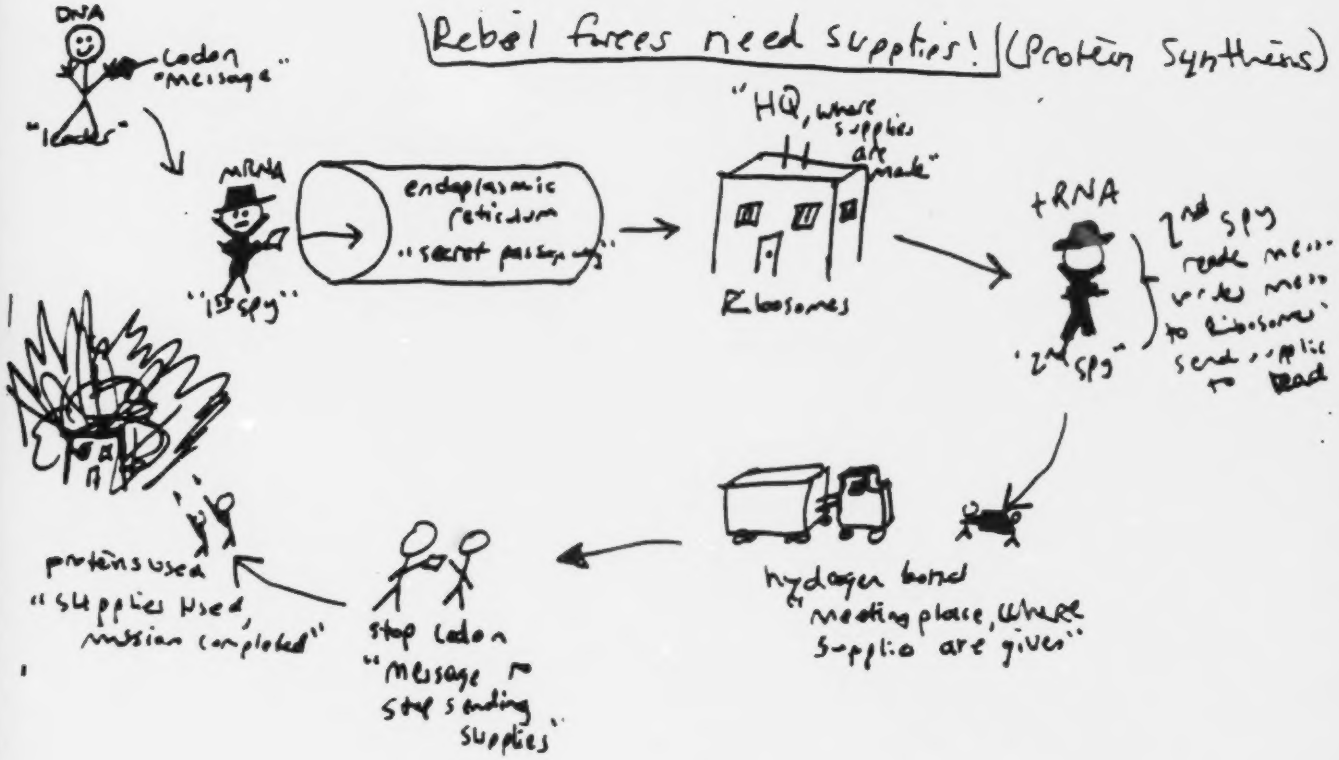
No clue, probably somewhere in the blood

Amino acids come from food, make protein.

Preconceptions test answers of student X before receiving instruction on protein synthesis.

Appendix R

Student X's Analogy


Rebel forces need supplies! (Protein Synthesis)
DNA
Codon "Message"
"leader"
mRNA
"1st spy"
endoplasmic reticulum
"secret passageway"
"HQ, where supplies are made"
Ribosomes
tRNA
"2nd spy"
2nd spy reads mess, writes mess to Ribosomes, send supplies to Read
hydrogen bond
"Meeting place, where supplies are given"
stop codon
"Message to stop sending supplies"
proteins used
"supplies used, mission completed"

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Appendix S

Student X's Explanation of Analogy

1 Replication -machine copies

2. - messenger takes message (codon)

3 - spy travels through - underground"

4. - spy goes to a HQ (with weapons)

5. - second spy reads code

6. - second spy delivers next code with supplies

7. - meeting place (hydrogen Bond)

8. - message to stop

9. -supplies are used

Amino Acids - guns, food, materials

Proteins - all supplies

hydrogen - meeting place

mRNA - first spy

DNA - leader, makes microchip

tRNA - second spy

Ribosomes - second HQ, supplies made here

Endoplasmic - underground

Codon - first message

Anticodons - second message

"Stop" Codon - stop making messages

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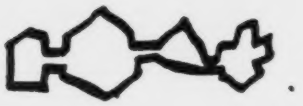
Appendix T

Student X's Alternative Conceptions-1 Month Posttest

1. What is a protein? Why are they important?

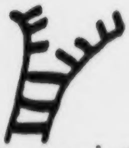
A protein is a group of assorted amino acids that looks like



They are necessary for reproduction of cells, provide vital nutrients, they help us sleep, grow, and do assorted things such as controlling allergies.

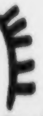
2. How are proteins made in the body?

①



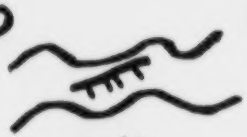
DNA unzips

②



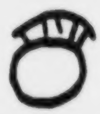
transcribes to mRNA

③



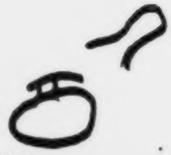
MRNA moves down endoplasmic reticulum

④



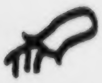
mRNA attaching to ribosomes

⑤



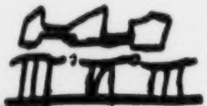
tRNA reads mRNA codons

⑥



tRNA goes into cytoplasm and finds anticodon!

⑦



each codon has an amino acid. together they make prot..

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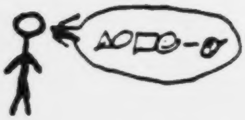
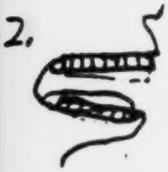
Appendix U

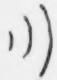
Analogy of Hearing-High Ability Male

1.


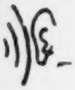
A foreigner speaks a message in his native tongue. (DNA)

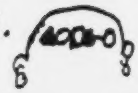
2.


The foreigner creates the sound waves by moving his mouth & tongue. (mRNA)

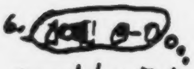
3.


The sound waves travel through the medium of air. (endoplasmic reticulum)

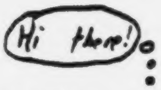
4.


5.


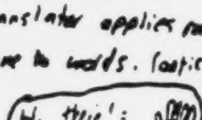
Translator mentally reads message. (tRNA)

6.


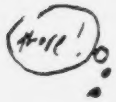
Translator reads the message in foreign words (codons)

7.


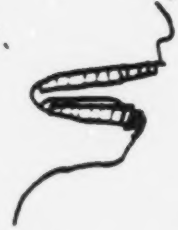
Translator applies native tongue to words. (anticodons)

8.


Translator applies meaning to message using thinking skills (amino acids, hydrogen bonds)

9.


Translator locates last word of sentence structure and is mentally translating.

10.


Translator says message so people can understand it.

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Appendix V

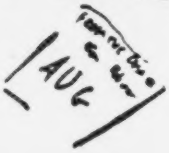
Analogy of a Lawyer's Office-High Ability Male

① THE LAWYER (DNA) TELLS HIS SECRETARY (mRNA) THAT HE NEEDS SOME RESEARCH DONE

② THE SECRETARY (mRNA) TAKES THE LAWYER'S NOTES (Codons) DOWN THE LAWFIRMS LONG HALLWAY (Endoplasmic Reticulum)

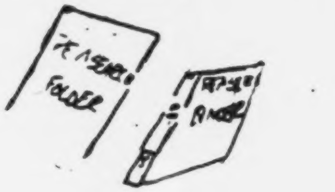
③ THEN THE SECRETARY EN THE LIBRARY (Landing o the ribosome)

④ THE LIBARAY CLERK (tRNA) TAKES THE NOTE AND BEGINS TO READ IT (Translation) into call letters (Codons)



⑤ THE CLERK BRINGS THE BOOKS TO MAKE THE REASEARCH REPORT (Anticodons)

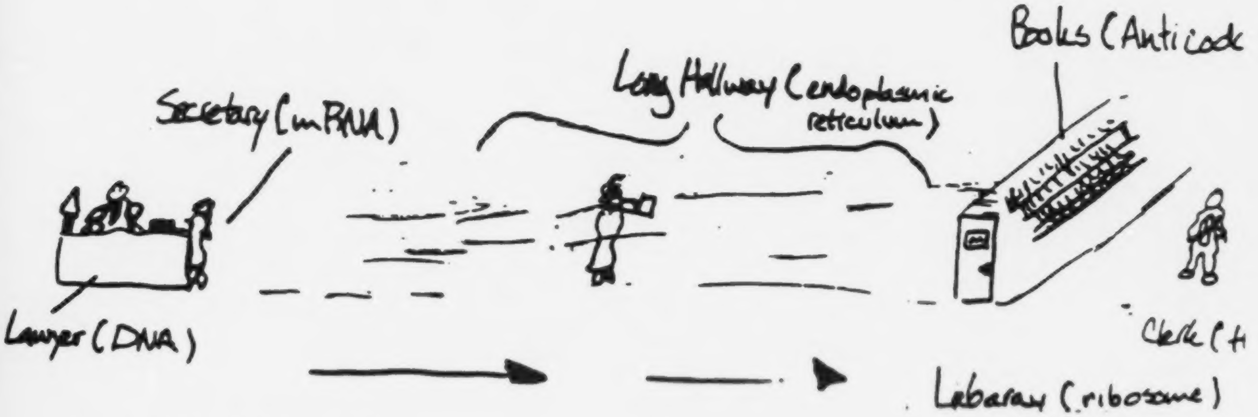
⑥ THE SECRETARY AND CLERK MAKE PHOTOCOPI OF THE NEED PAGES (Ami AND HOLD THEM TOGETHER WITH a Mark (Hydrogen bond) AND 3-ring b (Peptide bonds)


RESEARCH FOLDER
RESEARCH BINDER

⑦ WHEN THEY HAVE GATHERED THE REQUIRED INFORMATION, THEY STOP (UGA, stopcodon)

⑧ THEN THE SECRETARY MAILS THE COMPLETED RESEARCH (Protein) TO THE CLIENT

Diagram on back


Books (Anticod
Long Hallway (endoplasmic reticulum)
Secretary (mRNA)
Lawyer (DNA)
Clerk (t
Labaray (ribosome)

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Apply your analogy to the specifics of protein synthesis:

X Y(Your word) [✓ How is X like Y?] How is X different from Y?

Anticodon(books) Anticodon is made by the tRNA molecule to add to the codon to make to amino acids. The clerk (tRNA) finds the books (anticodon) which will be used to answer the lawyer's questions.

Codon(Lawyer's notes) Codon is the code words on the mRNA that give the instructions on which amino acids get used in what order. The secretary (mRNA) has the information (codons) from the lawyer's notes that the clerk (tRNA) is supposed to follow.

Amino Acids(Pages) Amino acids are the substances added to the new, growing protein chains. The research pages are the information gathered by the clerk (tRNA) as instructed by the lawyer (DNA)

Proteins(Research) Proteins are long molecules of small chains of small molecules called amino acids. The have ~~many~~ important functions. The final research requested and put together by the lawyer and his staff is complete.

Endoplasmic Reticulum(hallway) Endoplasmic reticulum is the passage that the mRNA takes to get from the nucleus to the ribosomes. The hallway is the passage that the secretary takes from the lawyers' office to the library.

Ribosomes(Library) Ribosomes are where the mRNA carries out its instructions to make poteins. The library is where the lawyer's secretary carries out her instructions.

mRNA(Secretary) mRNA is a genetic messenger that carries out the DNA orders. The secretary carries out the lawyer's orders

tRNA(Clerk) tRNA reads the mRNA's message and begins to make the protein chain. The clerk in the library reads the secretary's message and begins to work on the lawyers' research.

DNA(Lawyer.) DNA stores information and passes it on like a Lawyer has knoledge and shares it in his work.

Hydrogen Bonds (Folder) Hydrogen bonds are a peptide bond that holds the ~~[illegible]~~ anticodon and codon together. Folders mostly hold the information and research that the lawyer requested

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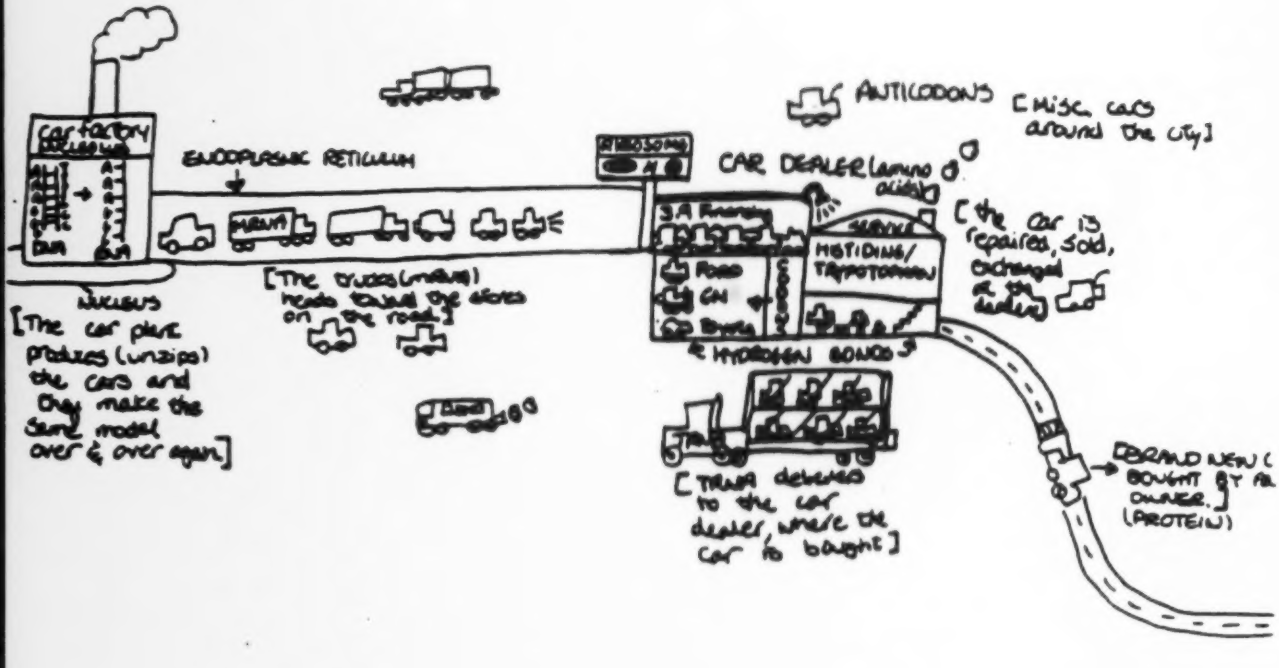
Appendix W

Literal Similarity of a City-High Ability Male


car factory
NUCLEUS
ENDOPLASMIC RETICULUM
mRNA
[The trucks (mRNA) heads toward the stores on the road.]
NUCLEUS
[The car plant produces (unzips) the cars and they make the same model over & over again]
RIBOSOMES
CAR DEALER (amino acids)
ANTICODONS
[Misc. cars around the city]
3 A Frames
Ford
GM
Toyota
SERVICE
HISTIDINE/
TRYPTOPHAN
[the car is repaired, sold, exchanged at the dealer]
HYDROGEN BONDS
tRNA
[tRNA delivers to the car dealer, where the car is bought]
[BRAND NEW (BOUGHT BY AN OWNER.] (PROTEIN)

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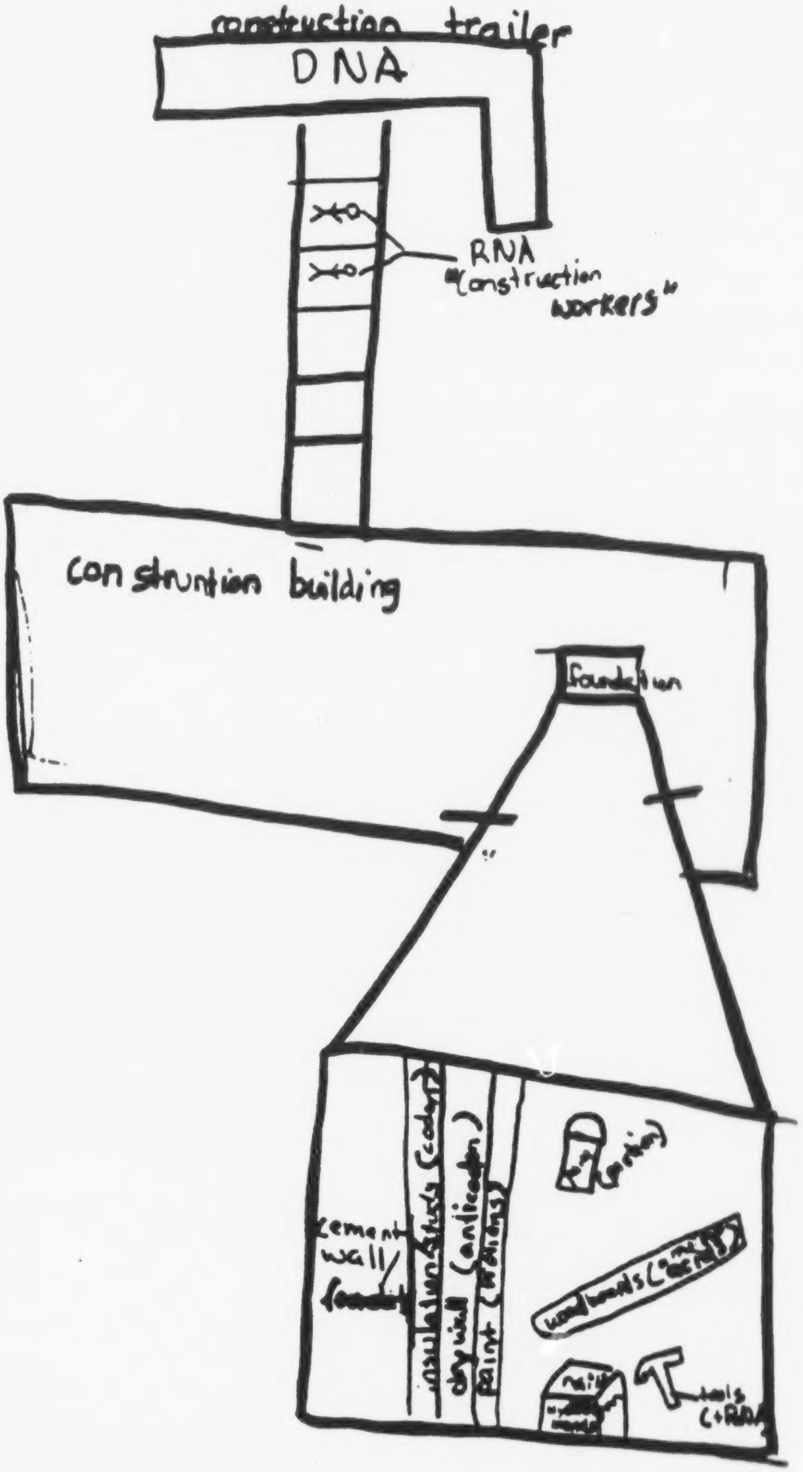
X	Y(Your word)	How is X like Y?
Anticodon	✓ Parts of Product	✓ Anticodons and codons are used to ~~make~~ the protein.
Codon	N Parts of Product	
Amino Acids	✓ Process of putting the product together	✓ Amino acids work to make the protein
Proteins	N Finished Product	N Proteins are the finished product of this work
Endoplasmic Reticulum	N Factory shipment	✓ - The mRNA is shipped through the endoplasmic reticu
Ribosomes	✓ Where the product is put together	N The work takes place on the ribosomes
mRNA	N Rough draft of product	N mRNA is the copy of the blueprint (DNA), like a rough draft
tRNA	✓ Editor, deliverer	✓ tRNA reads the codons and mRN and delivers anticodons
DNA	N Blue prints of the product	N DNA is the beginning (blue prints) of the product. ✓
Hydrogen Bonds	✓ Help product stay together (bonded)	put ~~product~~ together

Appendix X

Literal Similarity of a Construction Site-High Ability Male


construction trailer
DNA
RNA
"construction workers"
construction building
foundation
cement wall/
insulation&studs (codons)
drywall (anticodon)
paint (proteins)
(protein)
wood boards (amino acids)
nails
tools (+RNA

X	Y(Your word)	How is X like Y?	How is X different from Y?

Anticodon(drywall N) like- hooks N on to codon different- [illegible] can connect to a board,

Codon(studs & insulation N) like - starting N point different - insulation as studs not alway needed

Amino Acids(wood boards N) like - connect V to eachother different - boards can connect to other things

Proteins(paints N) like - finishing N touches different - paint not allways used

Endoplasmic Reticulum(cement N side-walk) like - bring V places together
different - side walk 2-way [illegible] -1 way

Ribosomes(foundation N) like - solid [illegible] V goes to [illegible] different - they hold until finished/workers leave at a same time

mRNA(workers N moving to job site) like - goes V to destination different - workers would do more

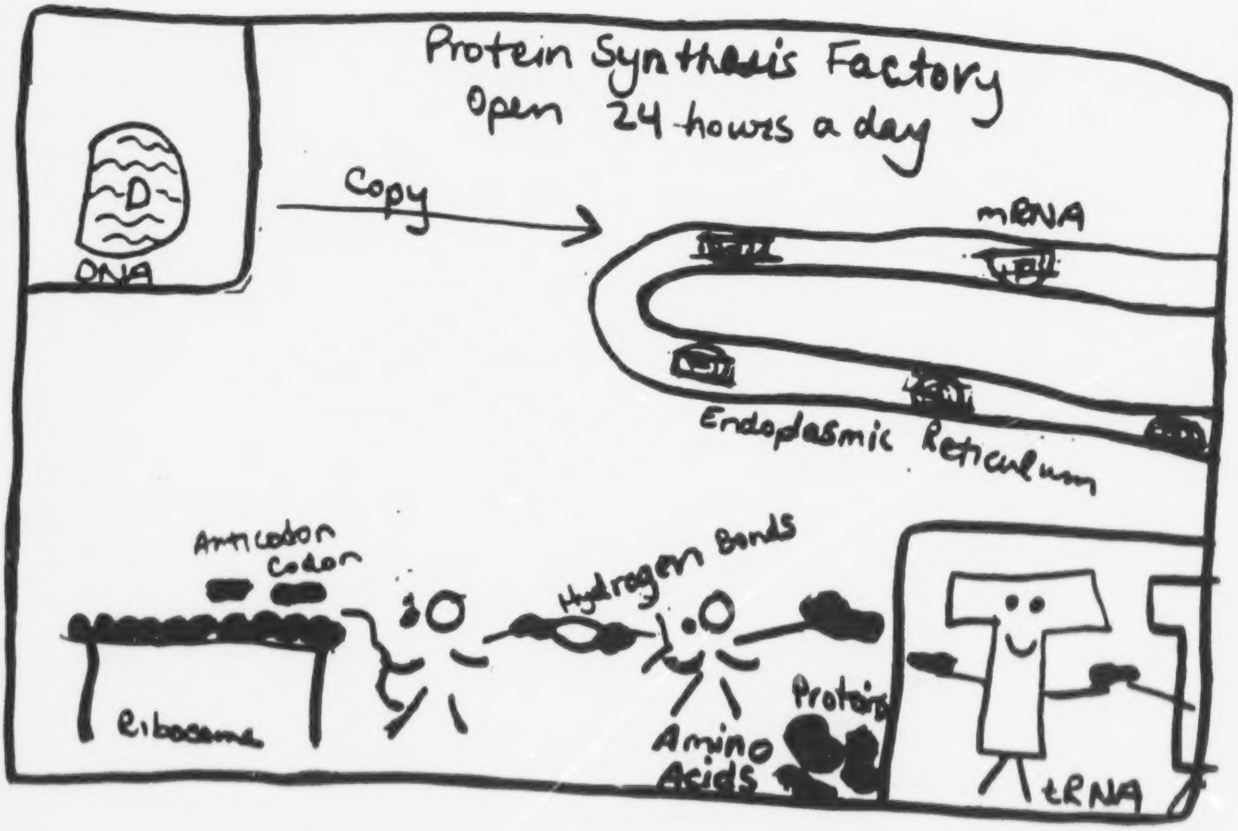
tRNA(tools N) like - holds things V together different - tRNA does more things

DNA(construction trailer N) like - blue prints N for cell or jobsite different - has [illegible]

Hydrogen Bonds (nails N) like - keeps things V together different - not in 1/3

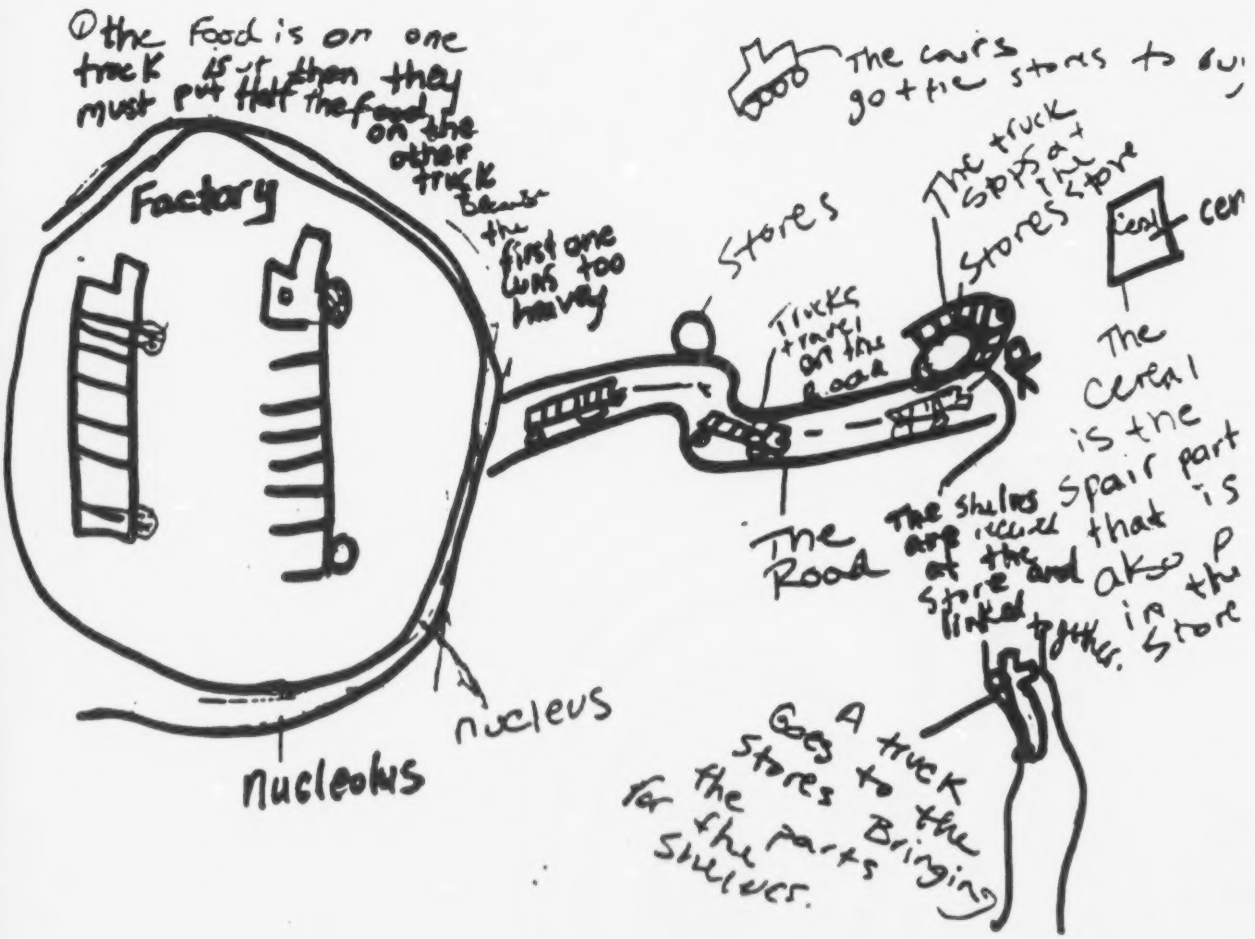
Appendix Y

Literal Similarity of a Factory-Low Ability Female


Protein Synthesis Factory
Open 24 hours a day
D
DNA
Copy
mRNA
Endoplasmic Reticulum
Anticodon
Codon
Hydrogen Bonds
Ribosome
Protein
Amino Acids
tRNA

Appendix Z

Literal Similarity of a Factory-Low Ability Female


① the Food is on one truck ~~is if~~ then they must put ~~Half~~ the food on the other truck Becaus the first one was too heavy
Factory
nucleus
nucleolus
Stores
Trucks travel on the Road
The Road
The cars go to the stores to bu
The truck stops at the store
Stores
cereal
cer
The cereal is the spair part that is also in the Store
The shelves are ... at the store and linked together.
A truck Goes to the Stores Bringing the parts for the shelves.

Apply your analogy to the specifics of protein synthesis:

X	Y(Your word)	How is X like Y?	How is X different from Y:
Anticodon(	cereal N)	spare parts N needed	You don't eat [illegible]
Codon(	Food N)	what the pack N of DNA [illegible] to the [illegible] or stores	Codon's are in triplets
Amino Acids(	parts of shelves W)	parts that are N going to be linked	Amino acids aren't shipped
Proteins(	Shelves W in store)	It's linked together N	The Proteins link on their own
Endoplasmic Reticulum(	Road W)	when the DNA travels V through	Roads have stop signs.
Ribosomes(	Food Stores N)	~~Stores~~ to the DNA or food	Stores aren't round
mRNA(	Truck W)	The Truck N or MRNA travels to store or Ribosomes.	Trucks don't split
tRNA(	Cars W)	goes to the stores V	Cars don't "Read"
DNA(	Truck W)	The original N truck	DNA don't sit in stores
Hydrogen Bonds (	people N)	Both come to V	H.B. don't go